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(54) Title: SOLID STATE GAMMA CAMERA (57) Abstract A gamma camera head comprising a plurality of signal sources, each associated with a pixel position, each said source producing a signal when a gamma ray absorption event occurs at or sufficiently close to its associated pixel, wherein said plurality of signal sources is associated with a contiguous extend of pixels; and a plurality of electronic circuits, each of which receives signals from at least two of the plurality of signal sources, wherein each said circuit receives said signals only from sources associated with con-contiguous pixels.		

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1 SOLID STATE GAMMA CAMERA2 FIELD OF THE INVENTION

3 The present invention relates to methods for reading
4 out a matrix of elements in a Solid State Gamma
5 Camera.

6 BACKGROUND OF THE INVENTION

7 The use of solid state detectors for the detection of
8 ionizing radiation is well known. Furthermore, the use of a
9 mosaic of groups of detector electrodes on a single
10 substrate of material such as CdZnTe has been mooted.

11 However, the application of such a matrix in a
12 practical gamma camera is nearly obviated by the lack of a
13 suitable fast readout system capable of reading out
14 individual counts from the very large array of detector
15 electrodes desirable for such a camera.

16 U.S. Patent 4,672,207 describes a readout system for a
17 mosaic of NXM scintillator/photodetector elements. In this
18 system the photodetectors feed row and column amplifiers
19 which indicate, for signals having the proper pulse height,
20 that an event has occurred in the nth row and the mth
21 column of the mosaic. However, this system requires a large
22 number of scintillator crystals and, if applied to the
23 solid state CdZnTe camera, as postulated above, would be
24 unable to discriminate events which occur near or at the
25 boundary between elements or to discriminate events which
26 result in Compton scattering events.

27 In published PCT Application WO 95/33332 a method of
28 reading out a matrix is described in which charge,
29 generated as a result of events at points in the matrix, is
30 stored at those points and the entire matrix is read out
31 seriatim. This method, although mooted as being useful for
32 a gamma camera utilizing CdZnTe, CdTe or a number of other
33 materials at pages 45-48, is not capable of distinguishing
34 individual events which would be necessary for the energy
35 discrimination of events, used, for example, to eliminate
36 events caused by Compton scattering.

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SUMMARY OF THE INVENTION

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It is an object of the present invention to provide a solid state gamma camera system having an improved readout system.

It is an object of some aspects of the present invention to provide a solid gamma camera system in which the outputs of individual pixels are recorded without the need to individually address the pixels.

It is an object of some aspects of the present invention to provide a solid state gamma camera in which events which occur near the boundaries of pixels and to some extent near the boundaries of crystals are properly detected.

It is an object of some aspects of the present invention to provide a solid state gamma camera in which the cells are all in a "talk-only" mode, in which no noise producing interrogating signals are necessary and in which each pixel transmits its data immediately after it detects an event.

It is an object of some aspects of the invention to provide a system which detects events which produce signals in more than one pixel, without collision of the data which is generated on these adjoining pixels.

A solid state gamma camera, in accordance with a preferred embodiment of the invention, is made up of a mosaic of crystals of CdTe (or alternatively of CdZnTe, HgI₂, InSb, Ge, GaAs, Si, PbCs, PbS or GaAlAs). One side of each crystal is preferably covered by a single, common, electrode and the other side of the crystal is preferably covered by a rectangular (preferably square) matrix of closely spaced electrodes. This matrix of electrodes defines the cells or pixels of the gamma camera image. In a preferred embodiment of the invention, the matrix comprises 16x16 elements having a size of 2x2 mm. However, the size of the elements and the matrix size may vary over a relatively wide range depending on the desired spatial resolution and count rate. In particular, crystal sizes of 1x1 to 4x4 mm appear to be reasonable in the practice of

1 the invention.

2 Generally, a rectangular mosaic of crystals each with
3 its associated matrix of elements is used to provide a
4 camera of the required size. This mosaic may have a
5 dimension of 20x20 crystals or greater.

6 When a gamma ray impinges on the crystal, energy which
7 is transferred to the crystal creates charge carriers
8 within the normally insulating crystal such that it becomes
9 temporarily conducting. When a high voltage is applied
10 between the electrodes in the matrix and the common
11 electrode, this charge generation results in current flow
12 between them. This current generally lasts between 50 and
13 600 nanoseconds, depending on the depth of penetration of
14 the gamma ray prior to its interaction with the crystal,
15 and the crystal quality. The total charge collected by the
16 matrix of elements is substantially proportional to the
17 energy of the absorbed gamma ray. In this regard, each
18 element can be considered as a signal source which produces
19 a signal when a gamma ray absorption event occurs at or
20 sufficiently close to its associated pixel.

21 In principle, the current resulting from a particular
22 event (i.e., an absorbed gamma ray) should be limited to a
23 single element of the matrix. However, a number mechanisms
24 act to cause current to be measured at, generally,
25 adjoining matrix elements.

26 One type of mechanism which induces current in more
27 than one electrode is when an event occurs at or near a
28 boundary between two or four matrix elements. Clearly, an
29 event which occurs precisely at the boundary will cause an
30 equal division of current between the adjacent two or four
31 electrodes. Furthermore, events which occur near a boundary
32 will also cause current to flow in adjoining elements since
33 the gamma ray creates a small, but finite cloud of charge
34 carriers which may overlap more than one cell and which
35 diffuses and widens during its travel toward the
36 electrodes. Thus, part of the current associated with an
37 event near the boundary will be detected in an adjacent
38 pixel element.

1 For each of the above effects, the energy of the gamma
2 ray is deposited at substantially one point in the crystal
3 and its effects are measured at more than one pixel
4 element. Some events do not deposit their energy at only
5 one point in the crystal. Rather they may undergo Compton
6 scattering so that a portion of their energy is deposited
7 at various points in the crystal. Each of these energy
8 deposits causes currents to flow in corresponding pixel
9 elements.

10 The above effects are dependent on both the energy of
11 the gamma ray photons and the depth of penetration of the
12 photon when it interacts with the crystal. Higher energy
13 photons produce a larger electron cloud and have a higher
14 probability of Compton scattering, such that, for 500 KeV
15 photons, less than half will deposit their energy at a
16 single point. The depth of penetration of the photon will
17 determine the amount of spreading of the electron cloud
18 prior to its being collected by one or more of the matrix
19 elements.

20 While there is a relatively large probability that
21 current will be collected in neighboring electrodes, the
22 probability that current will be collected by non-
23 neighboring electrodes is small, for the energies used in
24 Nuclear Medicine.

25 The determination of the position and energy of an
26 event, especially for the situation where more than one
27 matrix element receives current from the event, requires
28 that (i) current generated by each event be separately
29 received for each event and (ii) that the response at each
30 matrix element be separately received, or at least that all
31 currents for a particular event be added to give a proper
32 measure of the energy of the event. This would appear to
33 require that each pixel be connected, separately or in a
34 multiplex fashion, to the main data processing computer.
35 Such a connection would be impractical.

36 In accordance with a preferred embodiment of the
37 present invention a pre-processing and multiplexing unit is
38 attached to each crystal. This unit, referred to herein as

1 an "ASIC" unit, determines the distribution of charge
2 (i.e., energy) associated with each event and the position
3 of the event. For events whose charge is associated with
4 more than one pixel, the ASIC unit determines the amount of
5 charge associated with each of the pixels. It is this
6 reduced amount of information, namely, the energy
7 associated with each pixel which is involved in an event
8 and the position of each of these pixels which is
9 collected.

10 In accordance with a preferred embodiment of the
11 invention, the pixels on each crystal are grouped in K
12 identical rectangular groups of $n \times m$ pixels, designated p_i ,
13 ($i=1,2,\dots,K$) in a raster manner. The positions of the pixels
14 in each group are designated as P_j^i ($j=1,2,L=n \times m$) in a
15 raster manner. Thus, P_j^i completely define the pixel in the
16 crystal. The preconditioned voltages from electrodes having
17 the same value of i are connected to the inputs of the same
18 ASIC. Under normal circumstances, in which each element is
19 separately interrogated, $K \times n \times m$ lines would be needed.

20 The basis for a reduction in the number of lines
21 required to specify the position and strength of an event
22 in the crystal is based on the fact that most events
23 produce charge and current in one pixel and at most in 2-4
24 contiguous pixels. Thus if $n \times m$ is at least 2×2 , signals can
25 only be generated in no more than one pixel for each of the
26 K groups. The pixels may be in adjacent groups, however,
27 the i designation of the pixel in the adjacent groups will
28 be different for any event.

29 Each ASIC produces a coded output of the position of
30 the group from which the signal was received, a voltage
31 proportional to the charge generated at the electrode and,
32 preferably, an output which indicates that an event has
33 occurred.

34 For example, consider a crystal having a matrix of
35 16×16 pixels grouped into 64 (8×8) groups of 2×2 pixels.
36 Such a crystal has four ASICs, one for each position in the
37 group. Each ASIC (having 64 input lines, one for each
38 group) thus requires 8 output lines to completely describe

1 the portion of the charge generated at the electrodes. One
2 of the lines carries the signal amplitude (analog) and six
3 lines are required for the address. In addition a eighth
4 line preferably carries the "event occurred" signal.

5 Associated with each crystal is a module carrier which
6 carries the ASICs associated with the crystal, e.g., four
7 ASICs for the preferred embodiment. The total number of
8 lines need to specify the position and intensity of an
9 event in a crystal is thus, for the preferred embodiment,
10 $8 \times 4 = 32$ lines. While the number of "event occurred" lines
11 could be reduced by combining the signals from the various
12 ASICs, it is preferable to utilize a separate "event
13 occurred" line for each ASIC to avoid residual signals on
14 the other lines being considered by the computer.

15 It is understood that the time required to detect an
16 event internally inside the ASIC depends on the time
17 required to collect all the charge (a few hundred
18 nanoseconds to 1 microsecond or more depending on the
19 circuitry used). However, the time the lines are busy may
20 be much shorter, since this time can be as short as the
21 time it takes to stabilize the analog signal on the output
22 lines plus the time it takes for the A/D conversion at the
23 computer end. Using presently available components a "line
24 busy" time of 100 nanoseconds or even 50 nanoseconds is
25 easily attainable. This "line busy" time is the factor
26 which limits the rate of event collection. At the end of
27 this time the ASIC is preferably reset.

28 Generally, a gamma camera will comprise a number of
29 crystals in a mosaic. If the speed required of the camera
30 is slow, i.e., it is sufficient to detect one event per
31 event time cycle, a further reduction in the number of
32 lines from the camera into the computer can be achieved. In
33 this case the energy outputs from all the ASICs are summed
34 and the addresses are combined to give the address of the
35 events in a larger space. For additional crystals,
36 additional address lines will be required. Thus, if a
37 mosaic of 16×16 crystals is utilized, an additional 8 lines
38 will be required, bringing the total number of lines for

1 the preferred embodiment to $(8+8)*4=64$. These lines are
2 grouped into four identical buses of 16 lines each.
3 However, this reduction in lines may result in collisions
4 at rather low event rates.

5 The count rate of the system can be improved
6 substantially by further grouping of the crystals. For
7 example, if the crystals are grouped in groups of four
8 $(2*2)$, and the crystals having the same position are
9 grouped together, the system will require a total of
10 $[(6+8)*4]*4=224$ lines.

11 Further count rate improvement can be obtained by
12 increasing the size of the groups, thereby increasing the
13 number of lines required.

14 It is thus seen that the present invention allows for
15 a trade-off between the number of lines and the speed. In
16 general, 32 lines is sufficient for most systems.

17 It should be understood, that were the electrodes
18 connected directly to the computer, the number of lines
19 required for a system having a mosaic of $16*16$ crystals,
20 each having $16*16$ pixels would be 65536, a completely
21 unwieldy number. Even the use of multiplexing and fast
22 sampling would still require a very large number of lines.

23 The two most demanding applications for gamma camera
24 are first pass and coincidence modes. In first pass a
25 radio-isotope is injected into a vein leading to the heart.
26 The first pass of the nearly undiluted radioactive material
27 through the heart is measured to assess the heart function.
28 Since the measurement time is very short, high count rates
29 must be achieved in order to collect meaningful statistics.
30 Rates of 400,000 counts per second or more may be
31 encountered during first pass. Since the projection of the
32 heart is approximately 100 cm^2 the rate density is about
33 $4,000 \text{ counts/cm}^2\text{-sec}$. On the assumption that half the
34 events (on the average) split into two adjacent cells, the
35 rate of threshold crossing is one and one half times the
36 event rate or 600,000 counts per second (cps) for the
37 system and 600 cps/cm^2 .

38 On the individual cell level, where the size is very

1 small, even assuming a band pass filter with a time-
2 constant of 1 or several microseconds, there is no
3 practical limitation on the system rate.

4 On the ASIC level, the ASIC resets its channels once
5 the data is transmitted from one of its cells. If an event
6 is detected in one cell after another cell has crossed the
7 threshold, but before the other cell transmits its
8 information and resets the ASIC, that information will be
9 lost. This time is set by the one-shots of Fig. 10A at 420
10 nanoseconds, which leads to a nominal rate of 2.4×10^5
11 cps/ASIC. Since each ASIC serves 64 cells, the nominal
12 density is 9.4×10^4 cps/cm², which poses no problem in
13 achieving the required count rate.

14 On the system level, there are four buses, each is
15 busy for 100 nanoseconds while data is transmitted. This
16 leads to a maximum rate of 10^6 cps/buss or a system rate of
17 4×10^6 cps versus the 6×10^4 cps required. This would result
18 in an acceptable loss of counts. Alternatively, the busy
19 time of the busses can be reduced by at least a factor of
20 two by using faster A/D convertors.

21 Operation in a coincidence mode requires rates of up
22 to 10^6 per head. Since this is close to the limit for the
23 preferred embodiment, for such systems a smaller grouping
24 with a larger number of lines may be preferred.

25 The spatial response of a detector head comprised of a
26 multitude of discrete detector cells is space variant. A
27 small object placed above the cell center will produce an
28 image significantly different from one placed at the
29 boundary of two cells. A space invariant response can be
30 achieved by moving the detector cells with a controlled
31 motion parallel to the detector plane, such that the object
32 is viewed, preferably with equal probability by all points
33 in an area at least equal to the cell size. If this motion
34 is monitored and compensated for, preferably on the fly, on
35 an event by event basis, two performance improvements may
36 result:

37 a) the detector performance will be spatially
38 invariant with a resolution (separation power) of one cell.

1 b) the accuracy of location measurement will be equal
2 to that of the accuracy of the determination of the motion
3 of the head.

4 The dithering scan length should extend over at least
5 one cell, preferably over an integer number of cells, for
6 example one or two cells or more.

7 Data which is acquired at the varying positions of the
8 head is reframed into an image pixels which correspond to
9 fixed positions with respect to the patient. The size of
10 the image pixels is smaller than, and generally much
11 smaller than, that of the detector cells.

12 There is therefore provided, in accordance with a
13 preferred embodiment of the invention, a gamma camera head
14 comprising:

15 a plurality of signal sources, each associated with a
16 pixel position, each said source producing a signal when a
17 gamma ray absorption event occurs at or sufficiently close
18 to its associated pixel, wherein said plurality of signal
19 sources is associated with a contiguous extent of pixels;
20 and

21 a plurality of electronic circuits, each of which
22 receives signals from at least two of the plurality of
23 signal sources, wherein each said circuit receives said
24 signals only from sources associated with non-contiguous
25 pixels.

26 Preferably, at least two of the sources are connected
27 by a common connection, preferably a permanent common
28 connection to each of said plurality of sources.

29 There is further provided, in accordance with a
30 preferred embodiment of the invention, a gamma camera head
31 comprising:

32 a plurality of signal sources, preferably solid state
33 sources, each associated with a pixel position, each of
34 said sources producing a signal when a gamma ray absorption
35 event occurs at or sufficiently close to its associated
36 pixel;

37 an electronic circuit which receives non-multiplexed
38 signals from all of said sources; and

1 a plurality of signal lines connecting all of said
2 sources to said circuit, wherein at least one of said lines
3 connects more than one source to said circuit.

4 Preferably, the circuit comprises a plurality of
5 circuits, each of which is connected by a common
6 connection, preferably a permanent common connection, to at
7 least two of said plurality of signal sources.

8 Preferably, signal source is connected to only one of
9 said plurality of circuits.

10 In a preferred embodiment of the invention, each
11 electronic circuit produces a signal related to an energy
12 of the event whenever any of the signal sources from which
13 it receives signals produces a signal greater than a
14 predetermined threshold.

15 Preferably, said pixels are grouped into contiguous
16 groups of contiguous pixels and wherein each of said
17 plurality of circuits receives signals from only one pixel
18 in each group.

19 Preferably none of said plurality of circuits receives
20 said signals from contiguous pixels in two adjoining
21 groups.

22 In a preferred embodiment of the invention, the number
23 of said common connections is less than or equal to the
24 number of contiguous pixels in a group. Preferably, the
25 pixels are grouped in contiguous groups of contiguous
26 pixels and wherein each of said plurality of circuits
27 receives signals from only one pixel in each group.

28 There is further provided, in accordance with a
29 preferred embodiment of the invention, a gamma camera head
30 comprising:

31 a matrix of signal sources, preferably solid state
32 signal sources, each associated with a pixel position and
33 grouped into a plurality of geometrically similar groups,
34 each group having a plurality of contiguous pixel elements;
35 and

36 a plurality of electronic circuits, each of which
37 receives signals from one pixel element within each of a
38 plurality of groups, each said pixel element having a

1 similar geometric position within its respective group.

2 Preferably, each signal source produces a signal when
3 a gamma ray absorption event occurs at or sufficiently
4 close to its associated pixel position.

5 In a preferred embodiment of the invention, each
6 electronic circuit also produces at least one signal
7 indicating in which group of pixels the signal was
8 generated.

9 Preferably, each electronic circuit also produces at
10 least one signal indicating that an event has occurred, the
11 indicating signal preceding the energy signal in time.

12 In one preferred embodiment of the invention each
13 group comprises four pixel elements. In other preferred
14 embodiments of the invention each group comprises 2 or 9
15 pixel elements.

16 Preferably, the sources transmit said signals to said
17 circuit independent of any interrogating signal to the
18 sources.

19 Preferably, the sources are each associated with an
20 array of contiguous areas on the camera, such that said
21 signals represent events which occur at or near the
22 associated area and wherein said circuit identifies events
23 which generate signals in sources associated with two
24 neighboring areas.

25 In a preferred embodiment of the invention the signal
26 sources are associated with at least one normally
27 insulating crystal in which free charge is produced when a
28 gamma ray is absorbed therein. In a preferred embodiment of
29 the invention the signal sources comprise a matrix of
30 conductive elements on the crystal which collect the free
31 charge.

32 In a preferred embodiment of the invention the at
33 least one crystal comprises a mosaic of such crystals.

34 There is further provided, in accordance with a
35 preferred embodiment of the invention, a gamma camera for
36 imaging radiation emitted from or transmitted by an object,
37 comprising:

38 a gamma camera head having a front, input, surface,

1 and which produces signals when a photon associated with
2 the radiation is detected by the head, indicative of the
3 position of the detection on the input surface, at a given
4 resolution; and

5 a dithering system which differentially translates the
6 detector head or the object in at least one direction
7 parallel to the input surface by an amount at least equal
8 to the given resolution but less than 50 times the given
9 resolution during acquisition of the events.

10 There is further provided, in a preferred embodiment
11 of the invention, a gamma camera for imaging radiation
12 emitted from or transmitted by an object, comprising:

13 a gamma camera head having a front, input, surface,
14 and which produces signals when a photon associated with
15 the radiation is detected by the head, indicative of the
16 position of the detection on the surface, at a given
17 resolution; and

18 a dithering system which differentially translates the
19 gamma camera head or the object in two directions parallel
20 to the front surface by an amount at least as large as the
21 given resolution during acquisition of the signals.

22 Preferably the amount of differential translation is
23 greater than twice or four times the given resolution.

24 In a preferred embodiment of the invention, the gamma
25 camera includes circuitry which receives the signals and
26 an indication of the position of the head and which
27 distributes the events into an image matrix of pixels
28 having a matrix resolution finer than the given resolution,
29 said image matrix being referenced to the object.

30 Preferably, the event is distributed into an image
31 pixel having a reference point closest to a reference point
32 in the head, translated by the position indication.

33 In a preferred embodiment of the invention, events
34 acquired at a plurality of head positions having a distance
35 therebetween smaller than the given resolution are
36 distributed to said image matrix.

37 In a preferred embodiment of the invention, the gamma
38 camera includes an imaging system which provides an image

1 of the distribution of the detected radiation based on the
2 signals, the image having a second resolution which is
3 substantially constant over the surface.

4 There is further provided, a gamma camera for imaging
5 radiation emitted from or transmitted by an object,
6 comprising:

7 a gamma camera head having a front, input, surface,
8 and which produces signals when a photon associated with
9 the radiation is detected by the head, indicative of the
10 position of the event on the surface at a given resolution;
11 and

12 an imaging system which provides an image of the
13 distribution of the detected radiation based on the
14 signals, the image having a second resolution which is
15 substantially constant over the surface.

16 Preferably the second resolution is substantially
17 equal to the given resolution. The matrix resolution is
18 preferably finer than the given resolution by any factor,
19 for example by a factor of at least two or four.

20 In a preferred embodiment of the invention, radiation
21 sources, whose captured radiation is spaced by a distance
22 greater than the sum of the given resolution and the image
23 pixel, will be separately imaged as sources which have a
24 center spaced by the distance, substantially independent of
25 the position of the capture of the radiation on the
26 surface. Preferably, the image of a line source of constant
27 width will have a constant width along its length for any
28 inclination of the line on the surface. Preferably, the
29 image of two point sources will have a substantially
30 constant spacing independent of their position on the
31 surface.

32 In a preferred embodiment of the invention, the gamma
33 camera head comprises an array of detector elements,
34 preferably solid state detectors, which produce said
35 signals in response to the detection of the photons and
36 wherein the spacing of the elements is substantially equal
37 to the given resolution.

38 In a preferred embodiment of the invention the gamma

1 camera head incorporates an array of solid state detector
2 elements which produce said signals in response to the
3 detection of the photons.

4 There is further provided, in accordance with a
5 preferred embodiment of the invention, a gamma camera head
6 for imaging gamma rays emitted from or transmitted by an
7 object comprising:

8 a plurality of detectors, each having a physical
9 extent and spacings which define a physical resolution of
10 the head, each detector producing a signal when the head
11 detects a gamma ray which is associated with a cell in an
12 acquisition matrix having said physical resolution; and

13 an image matrix into which said events are
14 individually distributed, wherein said image matrix has a
15 resolution which is finer than the physical resolution.

16 Preferably, the image matrix is referenced to the
17 object and the distribution into the finer image matrix is
18 determined by the amount of the translation.

19 Preferably, the events are subsequently redistributed
20 into a second image matrix having a resolution different
21 from the image matrix or physical resolution.

22 In one preferred embodiment of the invention, the
23 second image matrix has a resolution which is poorer than
24 the physical resolution by a non-integral value.

25 There is further provided, in accordance with a
26 preferred embodiment of the invention, a gamma camera head
27 for imaging gamma rays emitted by or produced in an object
28 comprising:

29 a plurality of detectors, preferably, solid state
30 detectors, each having a physical extent and having a
31 spacing therebetween which define a physical resolution of
32 the head, each detector producing a signal when the head
33 captures a gamma ray which is associated with a pixel in an
34 acquisition matrix having said physical resolution; and

35 an image matrix into which said events are
36 distributed, wherein said image matrix has a resolution
37 which is poorer than the physical resolution by a non-
38 integral value.

1 There is further provided, in accordance with a
2 preferred embodiment of the invention, a gamma camera
3 comprising:

4 a gamma camera head as described above; and
5 an imaging system which provides an image of the gamma
6 rays based on the signals, having a resolution which is
7 substantially constant over the surface of the head.

8 The invention will be more clearly understood from the
9 following description of preferred embodiments thereof in
10 conjunction with the drawings in which:

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1 BRIEF DESCRIPTION OF THE DRAWINGS

2 Fig. 1 is a schematic drawing of a bottom view of a
3 crystal, in accordance with a preferred embodiment of the
4 invention, having a matrix of 16x16 electrodes;

5 Fig. 2 is a schematic isometric drawing of a crystal
6 module including ASICs, showing the top of the crystal of
7 Fig. 1, in accordance with a preferred embodiment of the
8 invention;

9 Fig. 3A is a schematic side view of a detector head
10 including a plurality of crystal modules mounted on a
11 mother board;

12 Fig. 3B is a schematic top view drawing of a portion
13 of the detector head of Fig. 3A;

14 Fig. 4A shows a connection scheme for a portion of
15 the electrodes on a crystal, in accordance with a preferred
16 embodiment of the invention;

17 Figs. 4B and 4C show alternative grouping schemes to
18 that of Fig. 4A having a greater and lesser number of
19 elements in each group;

20 Fig. 5A is a block diagram of the circuitry on a
21 module carrier for a single crystal, in accordance with a
22 preferred embodiment of the invention;

23 Fig. 5B is a more simplified block diagram of a single
24 crystal module;

25 Fig. 6A is a simplified circuit diagram of an analog
26 channel, in accordance with a preferred embodiment of the
27 invention;

28 Fig. 6B is a simplified block representation of the
29 circuit of Fig. 6A;

30 Fig. 6C shows the voltages and currents generated in
31 the circuit of Figs. 6A and 6B by an event;

32 Fig. 7A shows a peak and hold circuit in accordance
33 with a preferred embodiment of the invention;

34 Fig. 7B shows the input and output voltages generated
35 by the circuit of Fig. 7A for a particular current input;

36 Fig. 8 shows a simplified block diagram of a front end
37 portion of the ASIC, in accordance with a preferred
38 embodiment of the invention;

1 Fig. 9 is a 64 to 6 bit Address Encoder in accordance
2 with a preferred embodiment of the invention;

3 Fig. 10A shows the ASIC design logic in accordance
4 with a preferred embodiment of the invention;

5 Fig. 10B is the timing associated with the circuit of
6 Fig. 10A;

7 Figs. 11A and 11B are simplified block diagrams
8 showing the interconnection of modules on a motherboard in
9 accordance with one preferred embodiment of the invention;

10 Fig. 12 is a representation of an acquisition unit in
11 accordance with a preferred embodiment of the invention;

12 Fig. 13 is a block diagram of an acquisition board in
13 accordance with a preferred embodiment of the invention;
14 and

15 Fig. 14 shows, schematically, a system for providing a
16 uniform resolution for solid state gamma cameras.

17 PREFERRED EMBODIMENTS OF THE INVENTION

18 Reference is now made to Figs. 1-3 which show the
19 construction of a detector head 10 in accordance with a
20 preferred embodiment of the invention.

21 In general, in preferred embodiments of the invention,
22 a solid state gamma camera comprises detector head 10 which
23 is made up of a mosaic of crystals 12 of CdTe (or
24 alternatively of CdZnTe, HgI₂, InSb, Ge, GaAs, GaAlAs, PbS,
25 PbSC or Si), each preferably associated with a module 20.
26 One side of the crystal is preferably covered by a single,
27 common, electrode 18 and the other side of the crystal is
28 preferably covered by a rectangular (preferably square)
29 matrix of closely spaced electrodes 14. This matrix of
30 electrodes defines the cells or pixels of the gamma camera
31 image. In a preferred embodiment of the invention, the
32 matrix comprises 16x16 elements having a size of 2x2 mm.
33 However, the size of the elements and the matrix size may
34 vary over a relatively wide range depending on the desired
35 spatial resolution and count rate.

36 Generally, a rectangular mosaic of crystals each with
37 its associated matrix of elements is used to provide a
38 camera of the required size. This mosaic may have a

1 dimension of 16x16 crystals or greater.

2 Fig. 2 shows some details of one of modules 20, in
3 accordance with a preferred embodiment of the invention. In
4 particular Fig. 2 shows the common electrode 18, which
5 faces outwardly from the module, a crystal carrier 22 which
6 receives signals from electrodes 14 and which preferably
7 includes processing electronics for processing these
8 signals as described in detail infra. Connection pins 24 or
9 other means for electrically connecting the modules to the
10 rest of the gamma camera are also provided.

11 Fig. 3A shows one preferred method for connecting a
12 plurality of modules 20 to form a detector head 26. A
13 mother board 28 comprises a socket 30 for each module 20.
14 Socket 30 receives signals from pins 24 and transmits them
15 to the rest of the system via a plug 32. A pressure plate
16 34 and associated thin pressure providing springs 36 are
17 preferably provided to secure the modules in place and to
18 provide high voltage to the common electrode 18 associated
19 with each module.

20 As indicated above, a common system would have 16x16
21 pixels on each of a 16x16 mosaic of crystal elements. This
22 would lead to a matrix of 256x256 pixel elements.
23 Addressing such a matrix using prior art methods would
24 require a severe trade-off between the speed of the system
25 (if the elements were serially addressed) and the
26 complexity of the wiring if the pixels were addressed in
27 parallel.

28 In accordance with a preferred embodiment of the
29 invention, a method and apparatus for determining the
30 position of events on the detector head is provided which
31 combines high accuracy, high speed and reduced complexity.

32 Fig. 4A shows connections to the electrodes on a
33 crystal 12, in accordance with a preferred embodiment of
34 the invention. In this embodiment, the pixels (=electrodes)
35 are grouped in square 2x2 groupings 38 (delineated by
36 dotted lines), with each pixel in a group being marked with
37 one of the numbers 1-4 on Fig. 4. Similarly, each of the
38 groups is designated by reference numbers 1-64, there being

1 8x8 groups of 2x2 elements.

2 Each electrical connection to the elements is denoted,
3 in Fig. 4A and in the subsequent figures by a reference I_m^n ,
4 where n designates the position of the element within its
5 group and m is the number of the group. Each of the
6 elements in the first position, namely the 64 elements
7 numbered I_m^1 are connected to a first circuit called an ASIC
8 42 (shown in Fig. 5A), which is an acronym for Application
9 Specific Integrated Circuit. Similarly, each of the
10 elements in the other positions are separately connected to
11 respective ASIC for those positions. Thus, in this
12 preferred embodiment of the invention, the system includes
13 four ASICs, one for each of the four positions in the
14 group, with each ASIC having 64 inputs, one from each of
15 the groups of elements. The four ASICs are preferably
16 incorporated into crystal carrier 22, as indicated above.

17 Figs. 4B and 4C show two additional grouping schemes
18 for the pixels. In Fig. 4B a 3x3 grouping is shown having 9
19 pixels per group. This system requires 9 ASICs and has a
20 higher maximum rate than the system of Fig. 4A. Fig. 4B
21 shows a system with only two pixels per group. This system
22 while requiring fewer ASICs (only two) is proportionately
23 slower than the systems of Figs. 4A and 4B.

24 Fig. 5A and 5B are simplified and very simplified
25 schematic, functional block diagrams of receiver circuitry
26 40 contained in carrier 22, i.e., for each module 20, in
27 accordance with a preferred embodiment of the invention.

28 As indicated above, and as shown in Fig. 5A, each
29 module comprises four ASICs 42 each having 64 data inputs.
30 Each ASIC also receives a signal " T_r ", whose function is
31 described below and generates signals on eight lines H_p , A_q^p
32 and E_p where p is the number of the ASIC and q is a number
33 between 1 and 6. H is a signal which denotes if a signal
34 associated with an event has been generated in any of the
35 pixels associated with ASIC 42, the A lines identify the
36 pixel associated with the ASIC in which the signal has
37 been generated and E carries a, preferably analog, energy
38 signal denoting the energy associated with the pixel. The

1 group of 8 signal lines associated with the ASIC is denoted
2 by B_p .

3 Fig. 6A shows some of the circuitry, indicated by
4 reference number 44, associated with each pixel, contained
5 in ASICs 42. The circuitry is thus repeated 64 times in
6 each ASIC for the preferred embodiment described above.

7 A signal I_m^n generated by an element is fed to an
8 amplifier, preferably a charge to voltage amplifier 46. The
9 amplified signal is preferably filtered using a band-pass
10 filter 48, preferably an AC coupled low pass filter, which
11 reduces the noise in the signal. A peak detector (and hold)
12 circuit 50 is preferably used to detect and hold the peak
13 value of the signal generated by amplifier 46. Circuit 50
14 is preferably reset periodically with a reset signal,
15 RESET, which is generated elsewhere in the ASIC, as
16 described below.

17 A comparator circuit 52, compares the detected peak
18 signal with the threshold signal T_r and generates an "event
19 detected signal" "C" at position "5", if the detected
20 signal is greater than the threshold value. In addition,
21 the E signal, described earlier, is preferably the peak
22 value of the detected signal. A switch 54 is enabled by an
23 AND circuit 56 when the signal "3" is positive, i.e., when
24 the peak detected value is higher than the threshold value.

25 Fig. 6B shows a functional simplified version of
26 circuitry 44, referring to circuit 44 as a "Pix" circuit.

27 Fig. 6C shows the timing and signals developed by the
28 circuitry of Figs. 6A and 6B, where each of the signal
29 graphs is correlated with a particular test point in Fig.
30 6A. Signal "1" represents the current generated at a pixel
31 by the occurrence of an event either within the pixel or,
32 as described below, in a neighboring pixel. This current
33 is, in effect, integrated in current-to-voltage amplifier
34 46 to produce signal "2" (charge). After filtering, the
35 integrated signal becomes the more rounded signal "3" whose
36 peak is less sensitive to the noise level of the original
37 signal "2". The signal after the peak detector and hold
38 circuit 50 follows the filtered signal until the filtered

1 signal peaks and then holds that peak value. When the
2 filtered circuit passes the threshold value, the event
3 detected signal "C" is turned on as shown at "5." In
4 response to the event detected signal shown in "5" and an
5 enable signal shown in "6" is generated, and the energy
6 signal "E" appears at the output "7". Finally, after
7 detection of the event is complete, the reset signal, shown
8 in "8" clears the peak/hold circuit enabling detection of
9 the next event.

10 Fig. 7A shows the details of peak and hold circuit 50
11 in accordance with one embodiment of the invention, with
12 its response to an arbitrary signal (not one normally
13 encountered in the present use of the circuit) shown in
14 Fig. 7B. This circuitry is fairly common and any one of the
15 many ways to perform this function may be used in place of
16 the circuit of Fig. 7A. In the circuit shown in Fig. 7A,
17 the signal at its output will be the historical peak value
18 of its input for all times since the previous reset signal.
19 When a reset signal is received, the output voltage is set
20 at zero and, when the reset signal is removed, the output
21 will again represent the historical peak value.

22 Figs. 8 and 9 show a preferred methodology by which
23 the 64 Pix circuits 44 are interconnected to form front end
24 circuitry 52. As indicated above, each of the Pix circuits
25 44 receives a single signal from one of the pixels
26 associated with the particular ASIC. The E ("7") outputs
27 are tied together to form a single E signal. This is based
28 on the assumption that only a single event takes place in
29 the crystal during any one cycle (between the minimum time
30 between reset signals). For this assumption, only one of
31 the E outputs of the Pix circuits will be enabled and the
32 others will be zero. Thus the tying together of these
33 signals does not cause any loss of information regarding
34 the event.

35 Further, as shown in Fig. 8, the C signals are
36 preferably combined in an "or" circuit to generate the
37 previously mentioned reference H signal. The H signal thus
38 denotes that one of the 64 pixels associated with the ASIC

1 has generated a signal which may be associated with an
2 event.

3 Fig. 9 shows preferred encoder circuitry 55 (also
4 designated infra as ADRS circuitry) used to generate the
5 signals A_1 to A_6 , which as indicated above, identify which
6 pixel (actually the group containing the pixel) is
7 associated with the energy generated on the E line. This
8 circuitry may, of course, be replaced by other circuitry,
9 as known in the art, for generating the encoded address
10 signals A_1 to A_6 .

11 Fig. 10A shows a simplified block diagram of a
12 complete ASIC 42 made up of the functional elements
13 described above, together with additional circuitry. Fig.
14 10B shows the signals which are generated by ASIC, certain
15 of which are repeated from Fig. 6C. As described above,
16 front end 52 receives the 64 input signals associated with
17 the ASIC and generates the H, E and C signals. The H signal
18 feeds a "NOT" circuit 57 which changes the transitions of
19 the H signal from positive to negative transitions and
20 vice-versa. The "NOT"ed H signal is fed to a "one-shot" 58
21 which generates a 10 nanoseconds positive pulse when it
22 detects a negative going transition. Thus, the combination
23 of NOT circuit 57 and one-shot 58 produce a 10 nanosecond
24 pulse (signal "H" at "9") almost immediately after the
25 amplified signal "E" crosses the threshold value, T_r .

26 Figures 10A and 10B also show how the enable and reset
27 signals are generated. The output of one-shot circuit 58 is
28 fed to one shot circuits 60 and 62 which together operate
29 to produce, at the output of one-shot 62, the E_n pulse
30 which is a 100 nanosecond pulse which starts 300
31 nanoseconds after the end of the pulse from one-shot 58. A
32 one shot 64 produces a 10 nanosecond reset pulse following
33 the end of the enable pulse. Also shown on Fig. 10B are
34 preferred timing of the energy and position pulses
35 described above.

36 Two characteristics should be noted for the above
37 preferred embodiments. These characteristics are present
38 for those embodiments of the invention in which it is

1 desired to incorporate more fully events which take place
2 near the border between two pixels or in which the transfer
3 of energy from an incoming gamma ray takes place in two
4 steps, as described above, in the summary of the invention.

5 It is observed that, in almost all cases, the transfer
6 of energy (or more importantly, the generation of signals)
7 takes place in adjacent pixels, or, more rarely, in pixels
8 adjacent a corner. Thus, the method and apparatus described
9 above utilizing the ASICs of the invention allows for the
10 separate determination of the energy in each of the
11 possible pixels associated with a given event and of the
12 distribution of the energy among the pixels. This allows
13 for accurate energy discrimination among events, for all
14 events, including those events which generate signals in
15 two or more pixels. The threshold value T_r determines the
16 minimum signal (energy) per pixel which is to be considered
17 in the determination of the energy and position of an
18 event. In a preferred embodiment of the invention, the
19 threshold level is set at a low value, sufficient to block
20 signals which arise from noise and leakage signals
21 generated in the crystal. A threshold setting of several
22 percent of the total energy for a pulse may be suitable in
23 many situations. To the extent that noise and spurious
24 signals generated in the crystal are small, the
25 predetermined threshold could be zero or close to zero.

26 The position of an event whose signal is divided
27 between two pixels will be determined based on the measured
28 relative intensity of the signals and the source of the
29 division. For example, for relatively low energies, where
30 the major reason for energy division is the spreading of
31 the charge cloud which is generated, the position is
32 determined to be the pixel having the greatest signal
33 value. For very high energies, where two step energy
34 transfer is common, it may be desirable to place the event
35 in the pixel having the smaller signal, when that signal is
36 above a certain amplitude.

37 Fig. 11A shows how modules are interconnected, where
38 only one event at a time over the face of the detector head

1 is to be detected at any one time. In this case, the H line
2 is utilized to generate an additional 6 bits of position
3 information n_1^1 to n_6^1 . Fig. 11B shows this operation in a
4 more schematic form.

5 Fig. 12 is a partial schematic diagram of a "back end"
6 acquisition unit 66 of a gamma camera utilizing a detector
7 head as described above. Back end 66 receives the signals
8 generated by 1/4 of the pixels from the front end, namely
9 the "event detected" pulse, which precedes the other
10 pulses, the energy pulse and the encoded position signals,
11 a and n.

12 The event detected pulse is delayed by delay circuitry
13 68 and the delayed pulse is used to trigger an A/D circuit
14 74. The position signals are decoded by an address decoder
15 70 and this address is used to look up a correction factor
16 in look-up table 72. This correction is used, in energy
17 correction circuitry 76, to correct the (possibly) partial
18 energy generated in pixels which feed the acquisition unit
19 or due to pixel to pixel variations. This energy, together
20 with the position of the pixel on which it was detected,
21 are fed to CPU 80.

22 The above discussion has been limited to the case
23 where a single event happens during a measurement interval,
24 such as that shown in Fig. 10B. In the event that more than
25 one event occurs during a measurement interval, the signals
26 generated must be ignored. In addition, if the energy is
27 detected in more than one adjacent pixel, these energies
28 must be added and the sum of the energy used to determine
29 if an event is within a determined energy range, which
30 indicates a valid event.

31 These functions may be carried out in CPU 80 and in a
32 coincidence unit 84 shown in Fig. 13, which is a schematic
33 block diagram showing connection between the four
34 acquisition units 66 which make up the preferred embodiment
35 of the invention. Coincidence unit 84 receives the event
36 detected signals from all four acquisition units. If
37 multiple, closely spaced, signals are detected by the same
38 acquisition unit 66, coincidence unit 84 instructs main CPU

1 80 to ignore the event. If closely spaced and/coincident
2 signals are detected by different acquisition units, the
3 CPU is informed that it must take into consideration the
4 possibility that the signals may be from a single event (if
5 they are from adjacent pixels) or are the result of
6 separate events (if they are from non-adjacent pixels). If
7 the signals are from non-adjacent pixels, the energy
8 signals are treated as separate events. If they are from
9 adjacent pixels the energy signals are summed and form the
10 basis for determination of the acceptability of the event.
11 This acceptability is determined by comparing the summed
12 energy (or the energy from a single pixel, where only one
13 pixel produces a signal) to a range of energies to
14 determine if the event was probably produced by a primary
15 gamma ray. Such "windowing" is well known in the art.

16 In CPU 80, sensitivity correction, namely, a
17 correction for the spatially varying probability of
18 detection of events (caused by variations in either the
19 intrinsic sensitivity of the crystal or of the intrinsic
20 transmission of an overlying collimator) is performed. Many
21 methods of correction, such as partial event summation,
22 event skipping, event adding, etc. are known, and can be
23 used with the present invention.

24 Finally, for events which cause signals to be
25 generated in adjacent pixels, the true position of the
26 event must be determined. If the gamma ray energy is low,
27 the event should normally be assigned to the pixel with the
28 highest signal. If the energy is high, the event can be
29 divided between the various pixels, preferably based on a
30 computed probability that the event occurred in each of the
31 various pixels; or, the event can be placed in the pixel
32 with the lower signal, so long as that signal is greater
33 than some given value.

34 It should be appreciated that many variations are
35 possible on the above described systems, within the scope
36 of the invention. In particular, as mentioned in the
37 summary of the invention, various divisions of the pixels
38 into ASICs may be used. For example, more than 4 ASICs, for

1 example 9 ASICs for a 3x3 grouping of pixels, may be
2 used.

3 It is also possible to use fewer ASICs, utilizing a
4 single ASIC for more than one crystal, with each ASIC
5 having a greater number of input lines. In the extreme case
6 only 4 ASICs, each receiving signals from one-fourth of the
7 pixels (or 2 ASICs for the 2x1 system shown in Fig. 4C) is
8 possible, in principle.

9 Furthermore, the unit shown in Fig. 13 which, as
10 described, receives signals from the entire head, may be
11 used to receive signals from only a portion of the pixels.
12 This allows for multiple simultaneous events to be
13 acquired, so long as they do not occur in ASICs served by
14 the same acquisition unit. In this regard, it appears to be
15 desirable for each acquisition unit to be associated with
16 non-adjacent ASICs. This allows for more optimal
17 distribution of hot-spots among the acquisition units.

18 In addition, while the invention is described with
19 respect to a detector head having a mosaic of a large
20 number of particular types of crystals, this description
21 is based on a practical situation of crystal availability,
22 electronics reliability and manufacturing and service
23 considerations. However, the addressing methods which have
24 been described are equally applicable to any type of matrix
25 for the detection of gamma events utilizing a single
26 crystal or even one crystal per pixel. It is also
27 applicable to types of detectors other than crystals. In
28 the case of a single crystal or one crystal per pixel, it
29 would be possible to utilize a hexagonal matrix of the
30 pixels and only 3 ASICs.

31 Furthermore, the present invention is also applicable
32 to a gamma camera head utilizing a scintillator crystal
33 wherein the matrix of electrodes is replaced by a plurality
34 of photoreceptors which generate a signal in response to
35 light produced in the crystal by an event. Other sources of
36 signals related to gamma ray absorption events may also be
37 detected in accordance with the present invention.

38 Fig. 14 shows, very schematically, a head 100 of a

1 solid state gamma camera mounted on a dithering fixture
2 102. Dithering fixture 102 comprises a vertical dithering
3 arrangement 104, including a motor 106, which is operative,
4 in a preferred embodiment of the invention, to dither the
5 position of the head in a first direction, parallel to the
6 front surface of the head. Dithering fixture 102 also
7 comprises a horizontal dithering arrangement 108, including
8 a motor 110, which is operative to dither the position of
9 the head in a second direction parallel to the surface of
10 the head and perpendicular to the first direction. While
11 translation of the gamma camera head is most desirable
12 translation of the source of the gamma rays is also
13 possible.

14 Alternatively, a single motor may be used to perform
15 the dithering and a gear box may be used to provide
16 dithering in two directions.

17 The spatial response of a detector head comprised of a
18 multitude of discrete detector cells is space variant. A
19 small object placed above the cell center will produce an
20 image significantly different from one placed at the
21 boundary of two cells. A space invariant response can be
22 achieved by moving the detector cells with a controlled
23 motion parallel to the detector plane, such that the object
24 is viewed, preferably with equal probability by all points
25 in an area at least equal to the cell size. If this motion
26 is monitored and compensated for, preferably on the fly, on
27 an event by event basis, two performance improvements may
28 result:

29 a) the detector performance will be spatially
30 invariant with a resolution (separation power) of one cell.

31 b) the accuracy of location measurement will be equal
32 to that of the accuracy of the determination of the motion
33 of the head.

34 The dithering scan length should extend over at least
35 one cell, preferably over an integer number of cells, for
36 example one or two cells or more.

37 In operation, the dithering system changes the
38 position of the head in both directions such that during

1 any acquisition the position is moved over a distance of at
2 least one cell. However, the system is distinguished from
3 full body scanning systems in which the position of the
4 head is changed by a large amount, generally an amount
5 larger than the extent of the field of view of the camera
6 and always more than about 50 detector cell units. Since
7 the acquisition time for any view is relatively long and
8 the distance to be traversed is relatively small, such
9 position dithering is relatively easy to perform.
10 Preferably, the dithering steps are only a fraction of a
11 cell or the dithering motion is continuous.

12 Data which is acquired at the varying positions of the
13 head is reframed into image pixels which correspond to
14 fixed positions with respect to the patient. The size of
15 the image pixels is smaller and, generally much smaller,
16 than that of the detector cells.

17 In a first embodiment of the invention, data is
18 acquired continuously while the camera head is moved. In
19 this embodiment of the invention, if the size of the image
20 pixel is $1/n$ times the size of the detector cell, the
21 dithering is n times as fast in one direction as the other.

22 In a second embodiment of the invention, the camera
23 head moves in steps, each of which is $1/n$ of the physical
24 resolution element. In this embodiment of the invention,
25 the head moves by the increment in one direction and then,
26 while stationary in that direction it moves in a transverse
27 direction either in steps of $1/n$ or continuously such that
28 the time spent at each of the n transverse positions is the
29 same.

30 It should be noted that, for SPECT imaging, dithering
31 may only be required in the longitudinal direction.

32 During acquisition, the system computer (not shown in
33 Fig. 14), which receives both the detected event
34 information and information as to the dithering
35 displacement, reframes the data which is received into the
36 above-mentioned image pixels which correspond to fixed
37 positions with respect to the patient. In an especially
38 preferred embodiment of the invention, these image pixels

1 are substantially smaller (preferably by a factor of 2 or
2 more, and more preferably by a factor of 4-16) than the
3 actual detector cell size, which is generally limited by
4 the size of the solid state detectors themselves. This
5 division need not be an integral, i.e., the detector and
6 image pixel boundaries need not coincide.

7 By using such a dithering/rebinning system in
8 accordance with the invention, one of the outstanding
9 problems of solid state cameras, namely the non-uniform
10 resolution of the camera is overcome.

11 In particular, where the camera head utilizes an array
12 of detectors, the detectors have a physical size and
13 spacing (referred to herein as a "detector cell") which
14 define the ultimate resolution of the system and the
15 accuracy with which the position of an event can be
16 measured. When an event is acquired in a given detector
17 cell, the event is ascribed to a fixed point within that
18 cell, preferably, the center of the cell. The event is then
19 reframed into the image pixel having its center closest to
20 the center of the cell. While, in the preferred embodiment
21 of the invention, the position of image pixels and detector
22 cells are generally defined by their centers, other
23 definitions can be used in the practice of the invention.

24 In a further preferred embodiment of the invention,
25 synthetic image matrix elements are created by adding a
26 random number, preferably equal to or smaller than the
27 dithering step, to the actual position of the image pixel.
28 In this way, a matrix having a plurality of pixels for each
29 dithering element is created. This method is useful for
30 providing images of varying resolution based on the
31 acquired data.

32 In particular, absent the addition of the random
33 number, any rebinning of the data to achieve a resolution
34 which is not an integral multiple of the dithering step
35 would result in artifacts. If, for example, the dithering
36 step were 1.5 mm and an image having a resolution of 4 mm
37 were desired, rebinning of the data would result in non-
38 uniform resolution and sensitivity over the image.

1 One additional advantage of dithering in accordance
2 with this aspect of the invention is thus seen to be that
3 it allows for the generation of images having an integrally
4 or non-integrally better or poorer resolution than the
5 physical resolution, while preserving the uniform
6 resolution and sensitivity characteristic of the invention.

7 As is well known in the art, the point or line source
8 response of a solid state camera depends on the position of
9 the source with respect to the detector cell boundaries. A
10 diagonal line source, for example, will generally be imaged
11 as a "staircase" or a line having varying width due to this
12 varying resolution. When the dithering/reframing system of
13 the present invention is utilized, the resolution of the
14 system is constant over the entire face of the camera and
15 is substantially equal to the detector cell size.

16 Furthermore, while the system resolution is limited to
17 the size of the detector cell, and sources which are less
18 than one cell apart cannot be resolved, a system in
19 accordance with the invention is generally capable of
20 reliably distinguishing two counts which are spaced by a
21 fraction more than a single cell, so long as the fraction
22 is greater than the image pixel size. Moreover, while such
23 distances, when they are resolved in a prior art system,
24 are resolved in integral detector element spacings (such
25 that two sources spaced 1.5 cells apart may be imaged as
26 being in adjoining cells or spaced apart by a full cell),
27 in an image acquired according to the present invention,
28 point and line sources will be spaced by their true spacing
29 (to within the image pixel size). Thus, two point sources
30 which are 1.5 pixels apart will be imaged as two sources
31 having a width of 1 cell and a spacing between them of 0.5
32 cells, such that their centers are 1.5 cells apart. Of
33 course such a system does require that the electronics of
34 the system and the display be capable of handling and
35 displaying the higher image pixel resolution.

36 It should be clearly understood that, while in a
37 preferred embodiment of the invention, the
38 dithering/reframing system described may be used in

1 conjunction with a solid state gamma camera such as that
2 described above with respect to Figs. 1-13, dithering and
3 reframing is effective in producing the advantages of
4 uniform consistent resolution when used with any solid
5 state camera as is known in the art or with any camera in
6 which the pixels are delineated by a detector cell. For
7 example, the dithering/reframing system is equally
8 applicable to systems having a single scintillator crystal
9 for each detector and for systems in which a single crystal
10 is used for a plurality of sensors of the type described
11 above or of any other type. In particular, the invention
12 as described with respect to Fig. 14 is not meant to be
13 limited by the invention described with respect to Figs. 1-
14 13. However, the system is especially suited to non-anger
15 gamma cameras in which the physical spacing of detection
16 elements defines the resolution of the system.

17 The present invention has been described in detail
18 with respect to preferred embodiments thereof, however,
19 this description is not limiting as to the scope of the
20 invention which is defined by the following claims:

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CLAIMS

1. A gamma camera head comprising:

a plurality of signal sources, each associated with a pixel position, each said source producing a signal when a gamma ray absorption event occurs at or sufficiently close to its associated pixel, wherein said plurality of signal sources is associated with a contiguous extent of pixels;

and

a plurality of electronic circuits, each of which receives signals from at least two of the plurality of signal sources, wherein each said circuit receives said signals only from sources associated with con-contiguous pixels.

2. A gamma camera according to claim 1 wherein at least two of the sources are connected by a common connection to each of said plurality of sources.

3. A gamma camera head comprising:

a plurality of signal sources, each associated with a pixel position, each of said sources producing a signal when a gamma ray absorption event occurs at or sufficiently close to its associated pixel;

an electronic circuit which receives non-multiplexed signals from all of said sources; and

a plurality of signal lines connecting all of said sources to said circuit, wherein at least one of said lines connects more than one source to said circuit.

4. A gamma camera head according to claim 3, wherein the circuit comprises a plurality of circuits, each of which is connected by a common connection to at least two of said plurality of signal sources.

5. A gamma camera head according to claim 2 or 4, wherein said common connection is permanent.

6. A gamma camera head according to any of claims 1, 2, 4

1 or 5, wherein each signal source is connected to only one
2 of said plurality of circuits.

3

4 7. A gamma camera head according to any of claims 1, 2,
5 or 4-6 wherein each electronic circuit produces a signal
6 related to an energy of the event whenever any of the
7 signal sources from which it receives signals produces a
8 signal greater than a predetermined threshold.

9

10 8. A gamma camera head according to any of claims 2 or 4-
11 7 wherein said pixels are grouped into contiguous groups of
12 contiguous pixels and wherein each of said plurality of
13 circuits receives signals from only one pixel in each
14 group.

15

16 9. A gamma camera head according to claim 8 wherein none
17 of said plurality of circuits receives said signals from
18 contiguous pixels in two adjoining groups.

19

20 10. A gamma camera head according to claim 8 or claim 9
21 wherein the number of said common connections is less than
22 or equal to the number of contiguous pixels in a group.

23

24 11. A gamma camera head according to claim 10 wherein said
25 pixels are grouped in contiguous groups of contiguous
26 pixels and wherein each of said plurality of circuits
27 receives signals from only one pixel in each group.

28

29 12. A gamma camera head comprising:

30 a matrix of signal sources, each associated with a
31 pixel position and grouped into a plurality of
32 geometrically similar groups, each group having a plurality
33 of contiguous pixel elements; and

34 a plurality of electronic circuits, each of which
35 receives signals from one pixel element within each of a
36 plurality of groups, each said pixel element having a
37 similar geometric position within its respective group.

38

1 13. A gamma camera head according to claim 12 wherein each
2 signal source produces a signal when a gamma ray absorption
3 event occurs at or sufficiently close to its associated
4 pixel position.

5

6 14. A gamma camera head according to any of claims 8-13
7 wherein each electronic circuit also produces at least one
8 signal indicating in which group of pixels the signal was
9 generated.

10

11 15. A gamma camera head according to any of claims 8-14
12 wherein each electronic circuit also produces at least one
13 signal indicating that an event has occurred, the
14 indicating signal preceding the energy signal in time.

15

16 16. A gamma camera head according to any of claims 8-15,
17 wherein each group comprises four pixel elements.

18

19 17. A gamma camera head according to any of claims 8-15
20 wherein each group comprises nine pixel elements.

21

22 18. A gamma camera head according to any of claims 8-15,
23 wherein each pixel group comprises two pixel elements.

24

25 19. A gamma camera head in accordance with any of the
26 preceding claims, wherein said sources transmit said
27 signals to said circuit independent of any interrogating
28 signal to the sources.

29

30 20. A gamma camera head according to any of the preceding
31 claims said sources are each associated with an array of
32 contiguous areas on the camera, such that said signals
33 represent events which occur at or near the associated area
34 and wherein said circuit identifies events which generate
35 signals in sources associated with two neighboring areas.

36

37 21. A gamma camera according to any of the preceding
38 claims wherein the signal sources are solid state signal

1 sources.

2

3 22. A gamma camera head according to any of the preceding
4 claims wherein the signal sources are associated with at
5 least one normally insulating crystal in which free charge
6 is produced when a gamma ray is absorbed therein.

7

8 23. A gamma camera head according to claim 22 wherein the
9 signal sources comprise a matrix of conductive elements on
10 the crystal which collect the free charge.

11

12 24. A gamma camera head according to claim 22 or claim 23
13 wherein the at least one crystal comprises a mosaic of such
14 crystals.

15

16 25. A gamma camera for imaging radiation emitted from or
17 transmitted by an object, comprising:

18 a gamma camera head having a front, input, surface,
19 and which produces signals, when a photon associated with
20 the radiation is detected by the head, indicative of the
21 position of the detection on the input surface, at a given
22 resolution; and

23 a dithering system which differentially translates the
24 detector head or the object in at least one direction
25 parallel to the input surface by an amount at least equal
26 to the given resolution but less than 50 times the given
27 resolution during acquisition of the signals.

28

29 26. A gamma camera for imaging radiation emitted from or
30 transmitted by an object, comprising:

31 a gamma camera head having a front, input, surface,
32 and which produces signals, when a photon associated with
33 the radiation is detected by the head, indicative of the
34 position of the detection on the surface, at a given
35 resolution; and

36 a dithering system which differentially translates the
37 gamma camera head or the object in two directions parallel
38 to the front surface by an amount greater than the given

1 resolution during acquisition of the signals.

2

3 27. A gamma camera according to claim 25 or claim 26
4 wherein the amount of differential translation is greater
5 than twice the given resolution.

6

7 28. A gamma camera according to claim 27 wherein the
8 amount of differential translation is greater than four
9 times the given resolution.

10

11 29. A gamma camera according to any of claims 25-28
12 including circuitry which receives the signals and an
13 indication of the position of the head and which
14 distributes the events into an image matrix of pixels
15 having a matrix resolution finer than the given resolution,
16 said image matrix being referenced to the object.

17

18 30. A gamma camera according to claim 29 wherein the event
19 is distributed into an image pixel having a reference point
20 closest to a reference point in the head, translated by the
21 position indication.

22

23 31. A gamma camera according to claim 29 or claim 30
24 wherein events acquired at a plurality of head positions
25 having a distance therebetween smaller than the given
26 resolution are distributed to said image matrix.

27

28 32. A gamma camera according to any of claims 29-31 and
29 comprising an imaging system which provides an image of the
30 distribution of the detected radiation based on the
31 signals, the image having a second resolution which is
32 substantially constant over the surface.

33

34 33. A gamma camera for imaging radiation emitted from or
35 transmitted by an object, comprising:

36 a gamma camera head having a front, input, surface,
37 and which produces signals, when a photon associated with
38 the radiation is detected by the head, indicative of the

1 position of the event on the surface at a given resolution;
2 and

3 an imaging system which provides an image of the
4 distribution of the detected radiation based on the
5 signals, the image having a second resolution which is
6 substantially constant over the surface.

7

8 34. A gamma camera according to claim 32 or claim 33
9 wherein the second resolution is substantially equal to the
10 given resolution.

11

12 35. A gamma camera according to any of claims 32-34
13 wherein the image is provided in an image matrix having a
14 matrix resolution finer than the given resolution.

15

16 36. A gamma camera according to any of claims 32-35
17 wherein the matrix resolution is at least twice as fine as
18 the given resolution.

19

20 37. A gamma camera according to claim 36 wherein the
21 matrix resolution is at least 4 times as fine as the given
22 resolution.

23

24 38. A gamma camera according to any of claims 32-37
25 wherein radiation sources whose captured radiation is
26 spaced by a distance greater than the sum of the given
27 resolution and the image pixel, will be separately imaged
28 as sources which have a center spaced by the distance,
29 substantially independent of the position of the capture of
30 the radiation on the surface.

31

32 39. A gamma camera according to any of claims 32-38
33 wherein the image of a line source of constant width will
34 have a constant width along its length for any inclination
35 of the line on the surface.

36

37 40. A gamma camera according to any of claims 32-39
38 wherein the image of two point sources will have a

1 substantially constant spacing independent of their
2 position on the surface.

3

4 41. A gamma camera according to any claims 25-40 wherein
5 the gamma camera head comprises an array of detector
6 elements which produce said signals in response to the
7 detection of the photons and wherein the spacing of the
8 elements is substantially equal to the given resolution.

9

10 42. A gamma camera according to claim 41 wherein the
11 detector elements are solid state detectors.

12

13 43. A gamma camera according to any of claims 25-41
14 wherein the gamma camera head incorporates an array of
15 solid state detector elements which produce said signals in
16 response to the detection of the photons.

17

18 44. A gamma camera head for imaging gamma rays emitted
19 from or transmitted by an object comprising:

20 a plurality of detectors, each having a physical
21 extent and spacings which define a physical resolution of
22 the head, each detector producing a signal when the head
23 detects a gamma ray which is associated with a cell in an
24 acquisition matrix having said physical resolution; and
25 an image matrix into which said events are
26 individually distributed, wherein said image matrix has a
27 resolution which is finer than the physical resolution.

28

29 45. A gamma camera head according to claim 44 wherein the
30 image matrix is referenced to the object and wherein the
31 distribution into the finer image matrix is determined by
32 the amount of the translation.

33

34 46. A gamma camera head according to claim 44 or claim 45
35 wherein the events are subsequently redistributed into a
36 second image matrix having a resolution different from the
37 image matrix or physical resolution.

38

1 47. A gamma camera head according to claim 46 wherein the
2 second image matrix has a resolution which is poorer than
3 the physical resolution by a non-integral value.

4

5 48. A gamma camera head for imaging gamma rays emitted by
6 or produced in an object comprising:

7 a plurality of detectors, each having a physical
8 extent and having a spacing therebetween which define a
9 physical resolution of the head, each detector producing a
10 signal when the head captures a gamma ray which is
11 associated with a pixel in an acquisition matrix having
12 said physical resolution; and

13 an image matrix into which said events are
14 distributed, wherein said image matrix has a resolution
15 which is poorer than the physical resolution by a non-
16 integral value.

17

18 49. A gamma camera head according to any of claims 44-48
19 wherein the detectors are solid state detectors.

20

21 50. A gamma camera comprising:

22 a gamma camera head according to any of claims 44-49;
23 and

24 an imaging system which provides an image of the
25 generated gamma rays and based on the signals, having a
26 resolution which is substantially constant over the surface
27 of the head.

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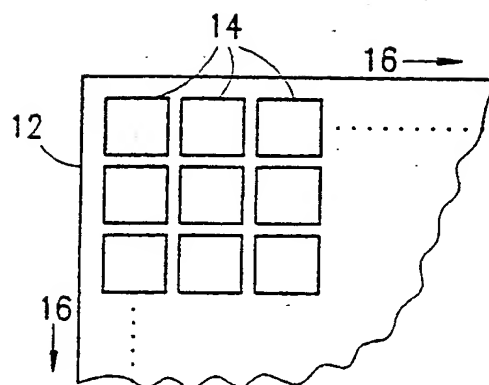


FIG. 1

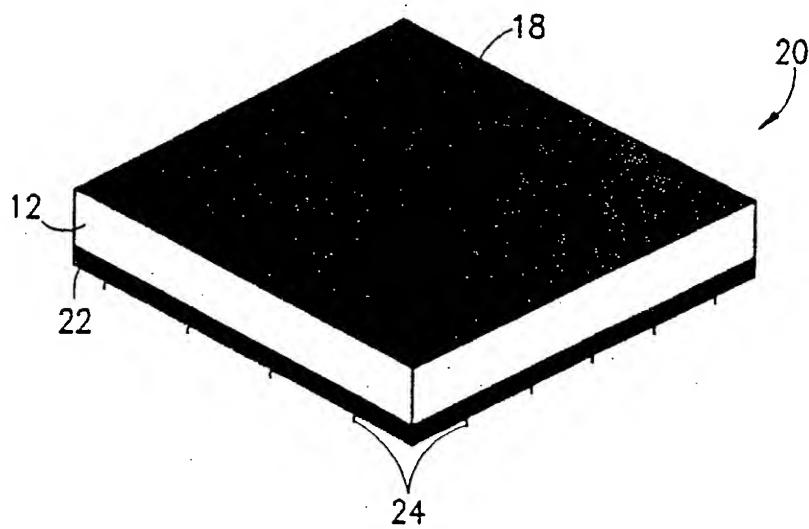


FIG. 2

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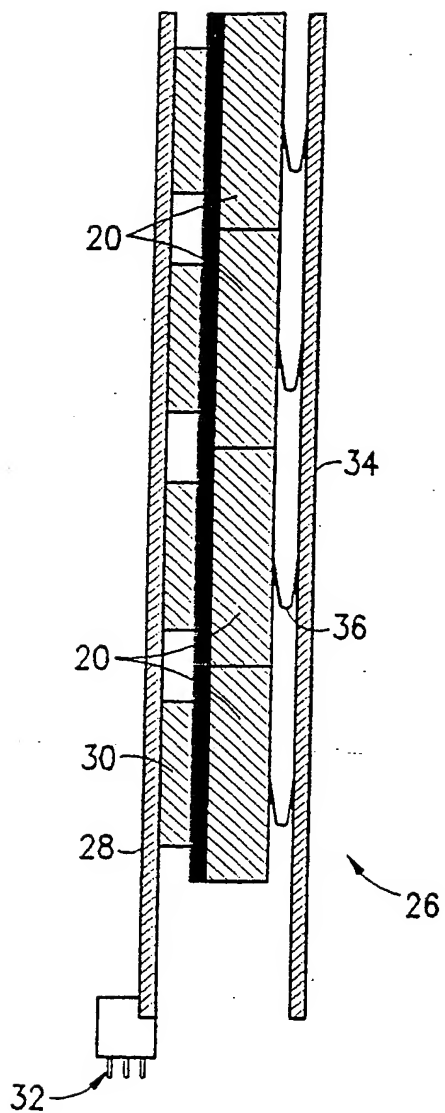


FIG. 3A

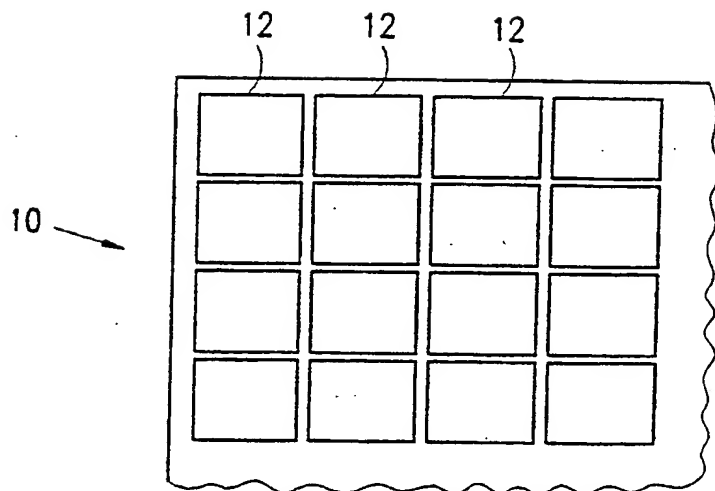


FIG. 3B

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FIG. 4A

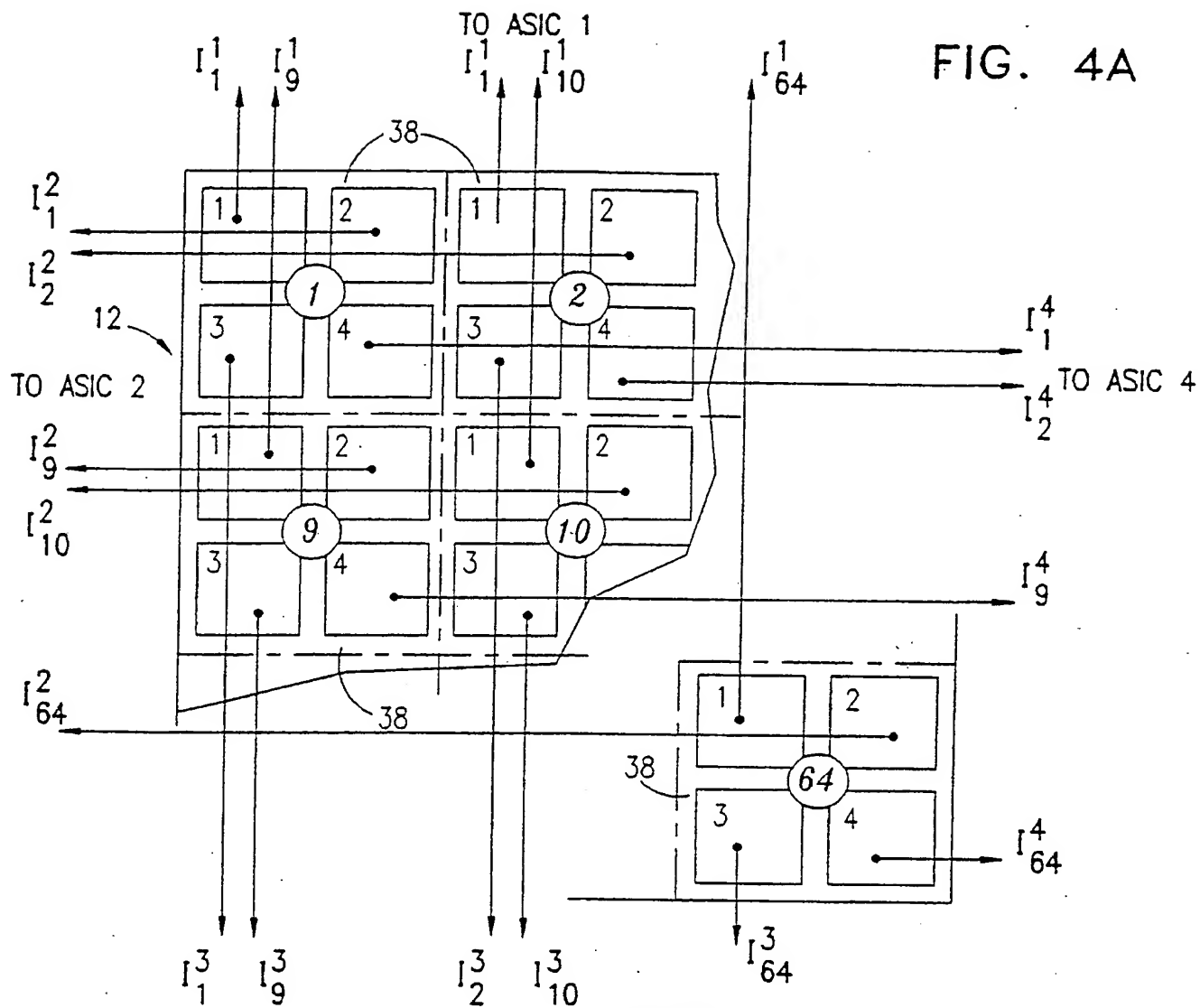
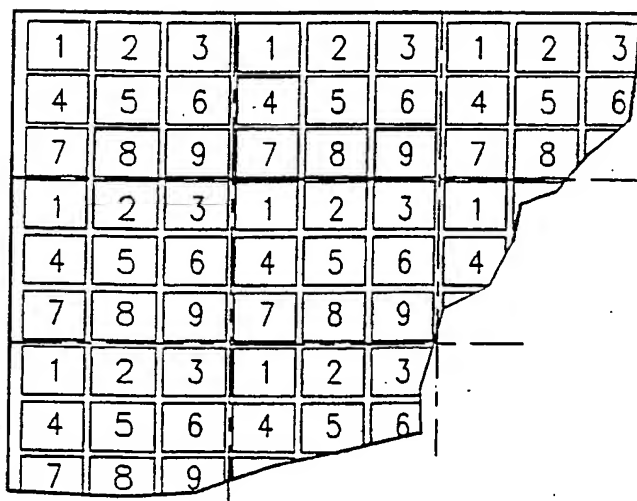
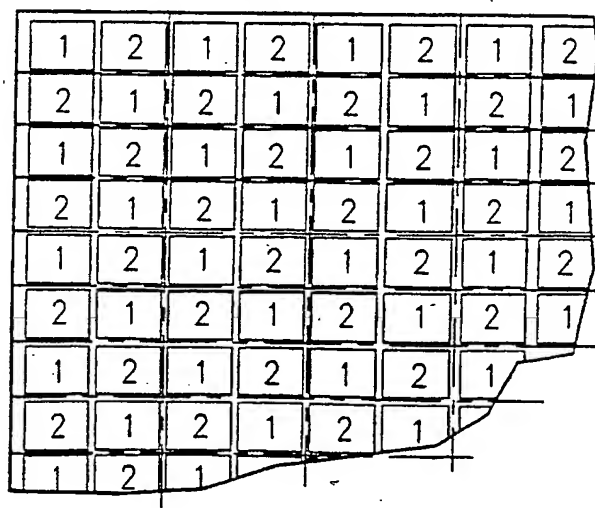


FIG. 4B



TO ASIC 3

FIG. 4C



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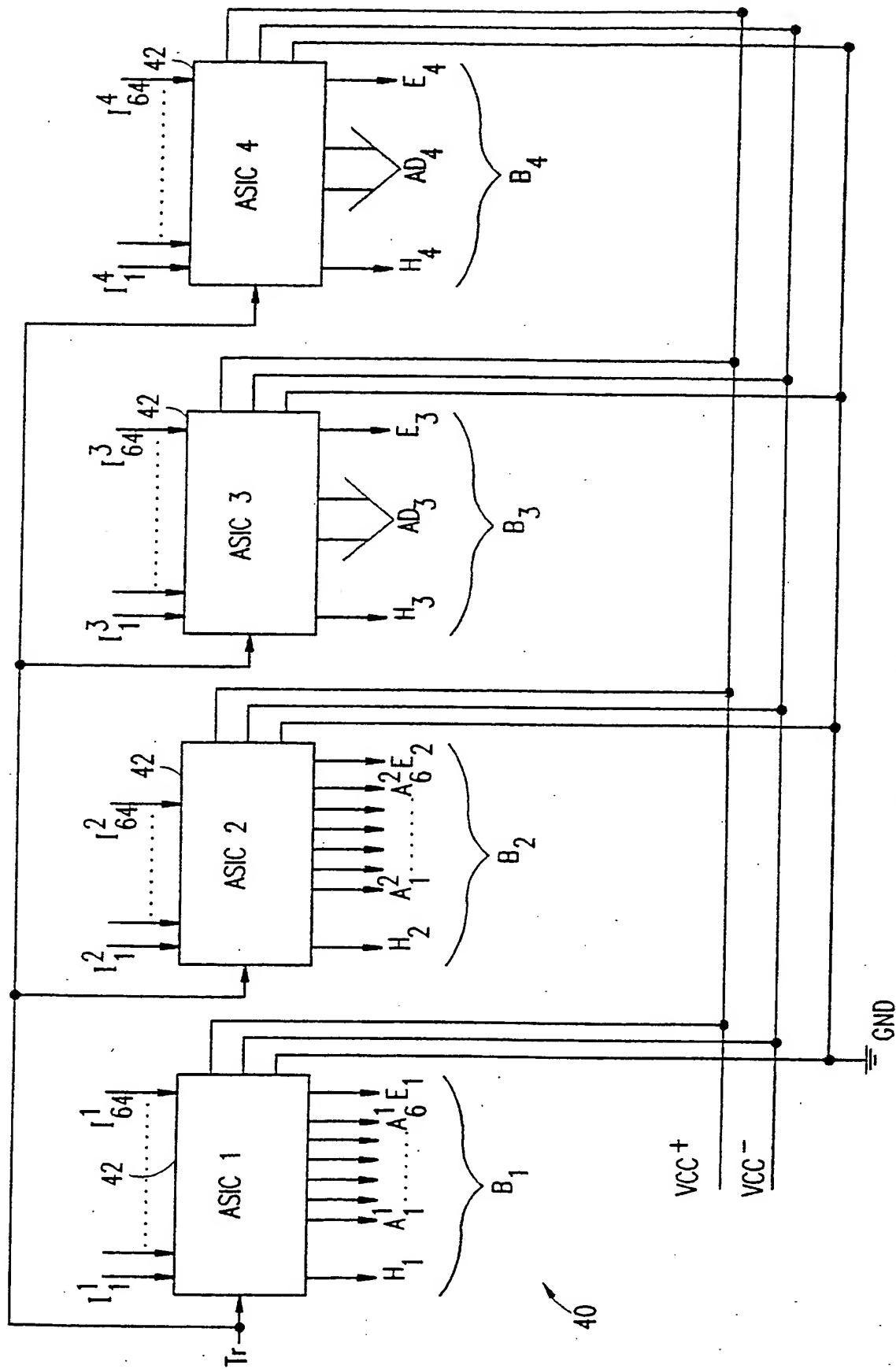


FIG. 5A

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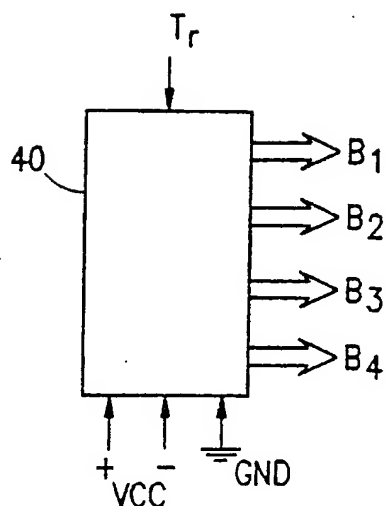


FIG. 5B

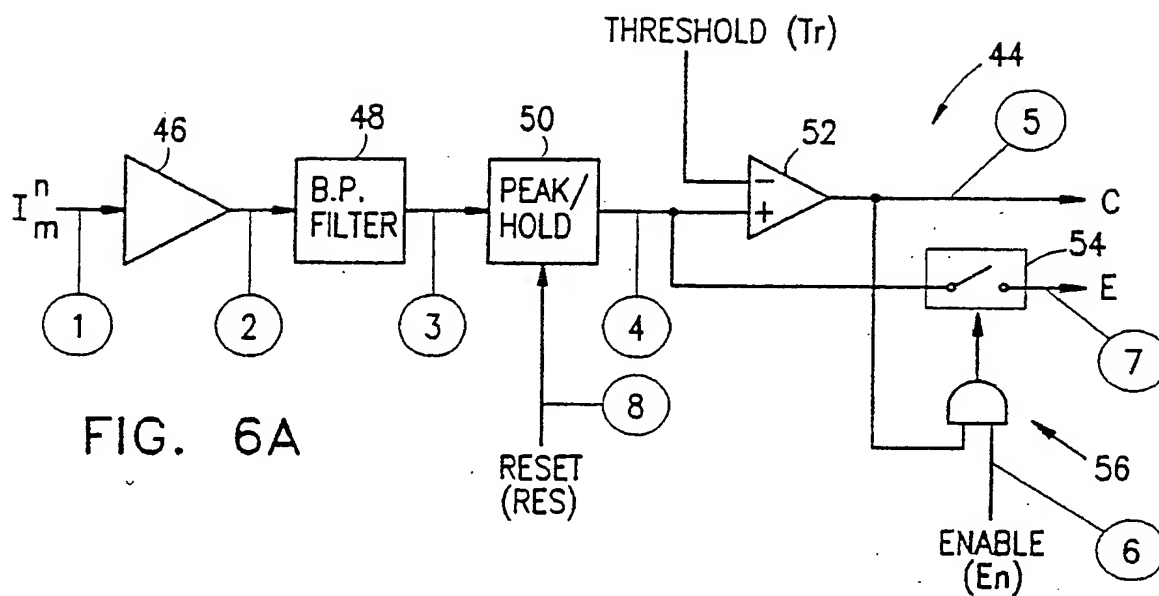


FIG. 6A

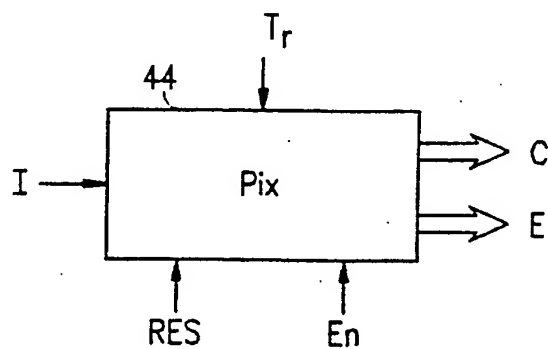
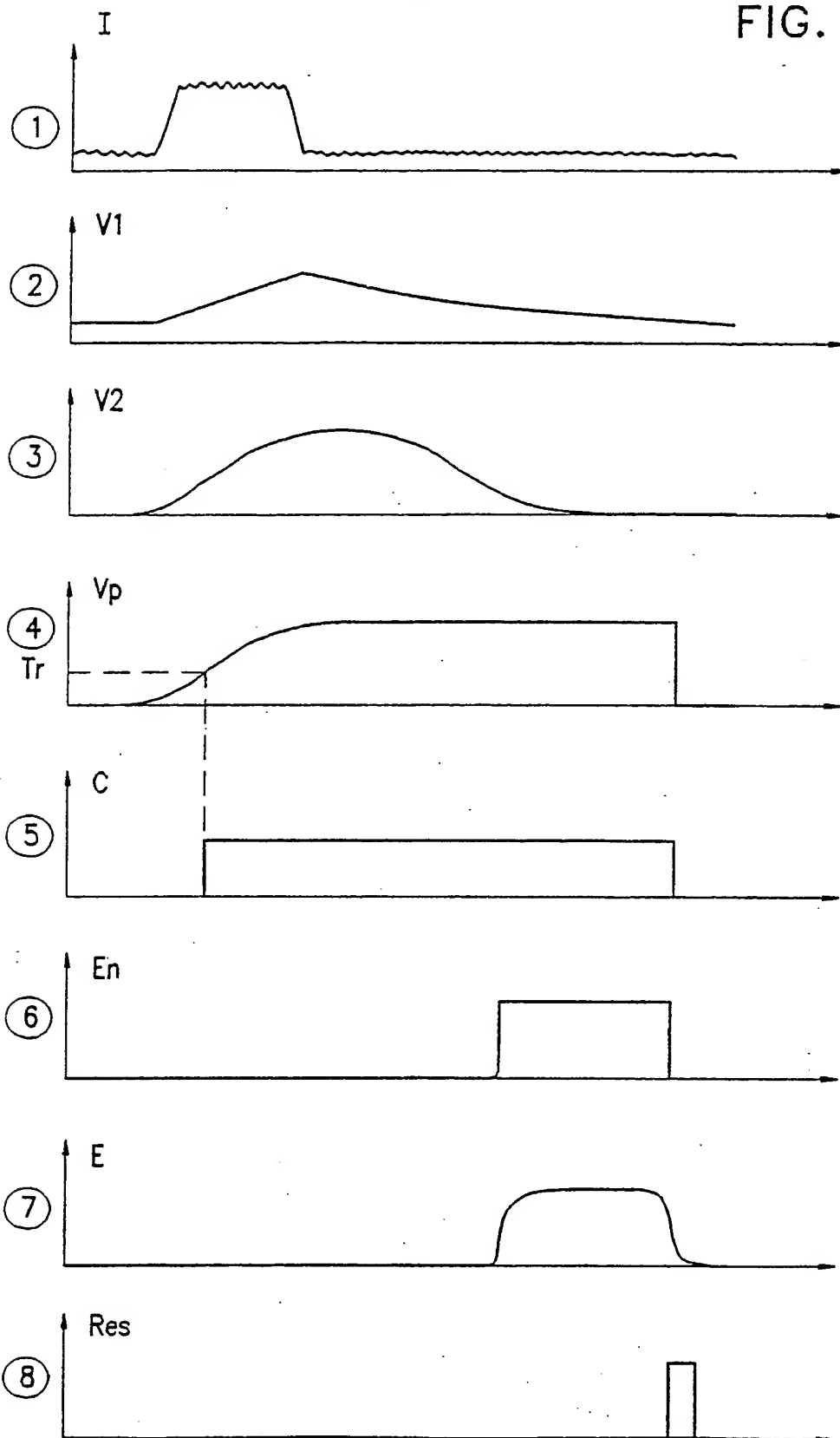


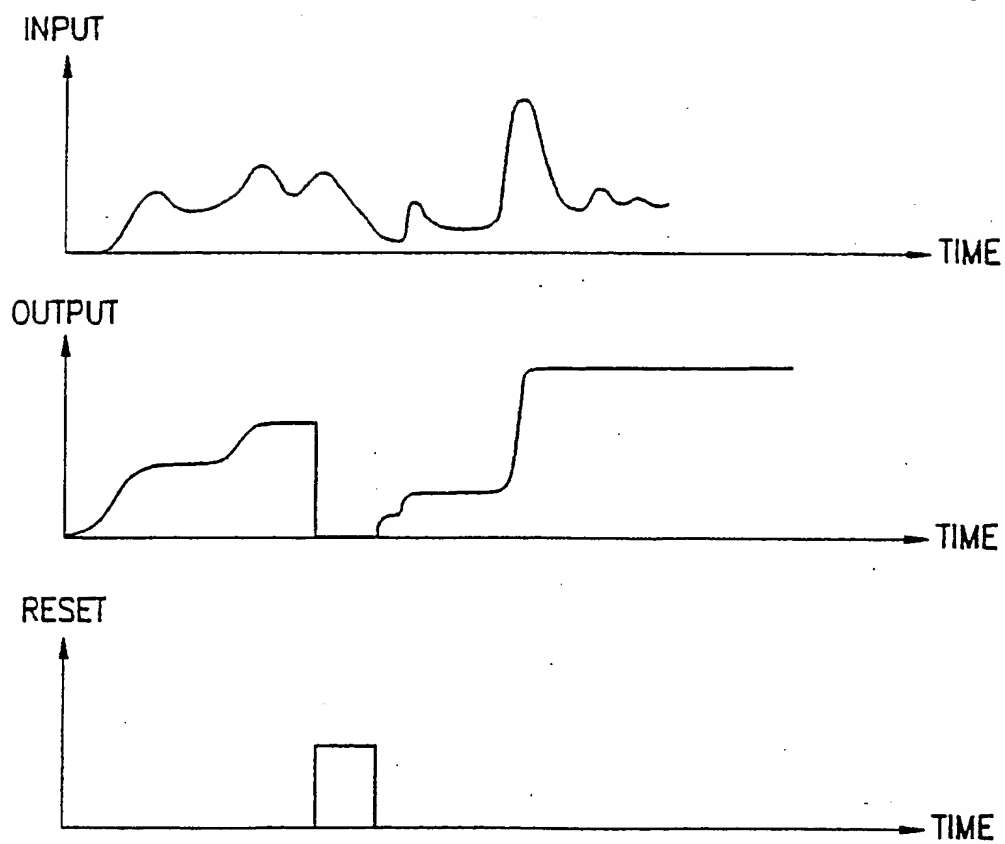
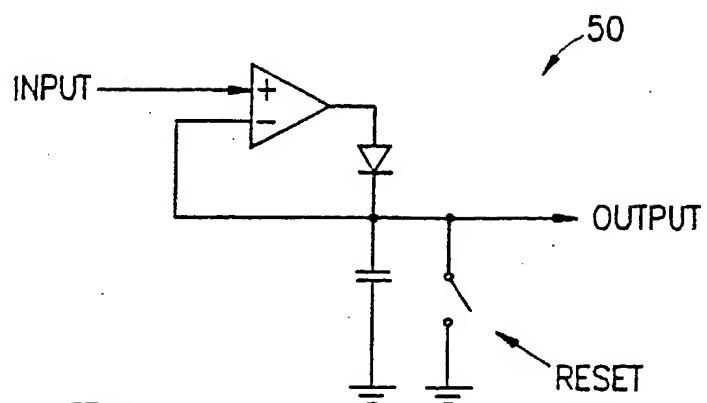
FIG. 6B

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FIG. 6C



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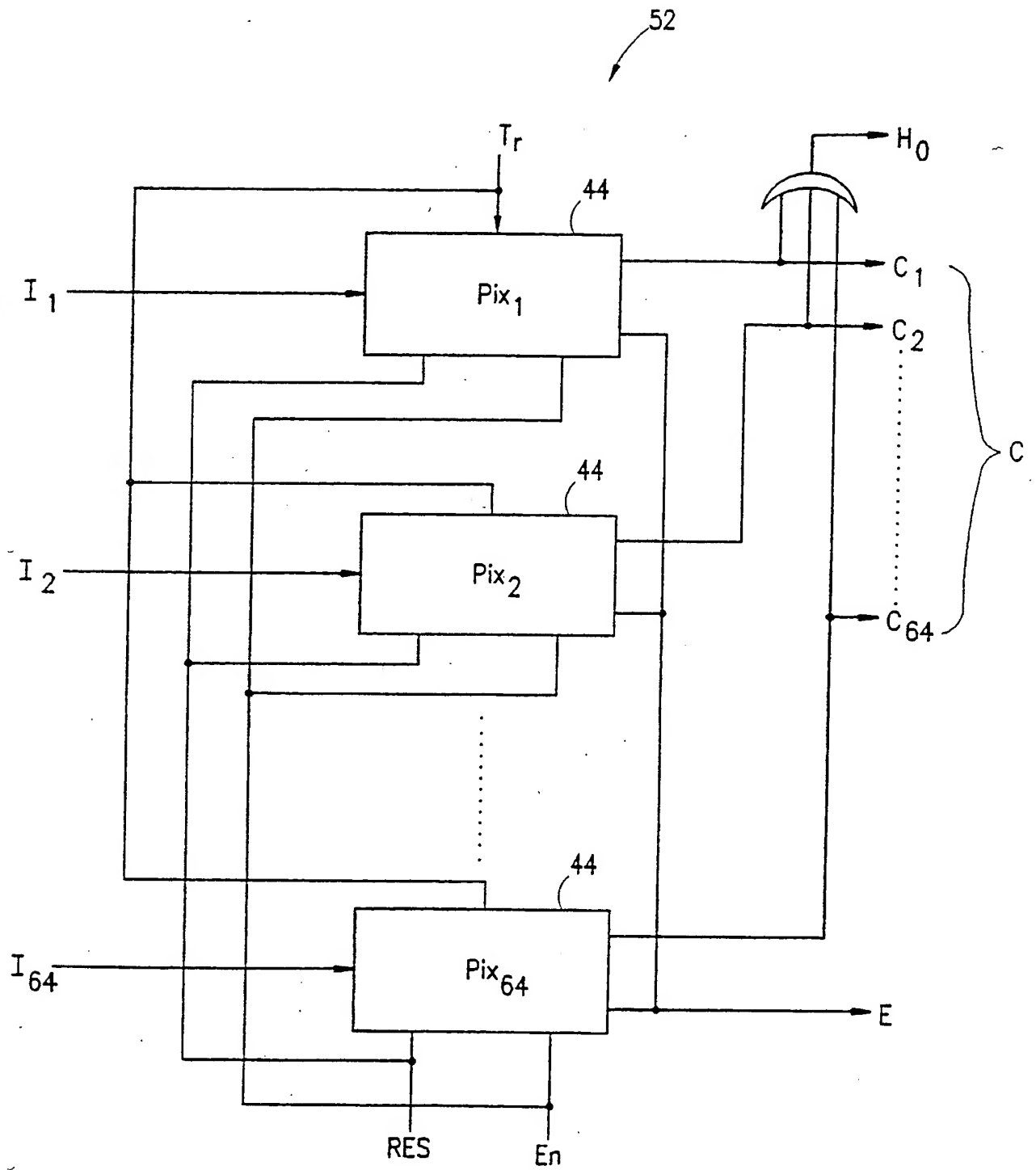


FIG. 8

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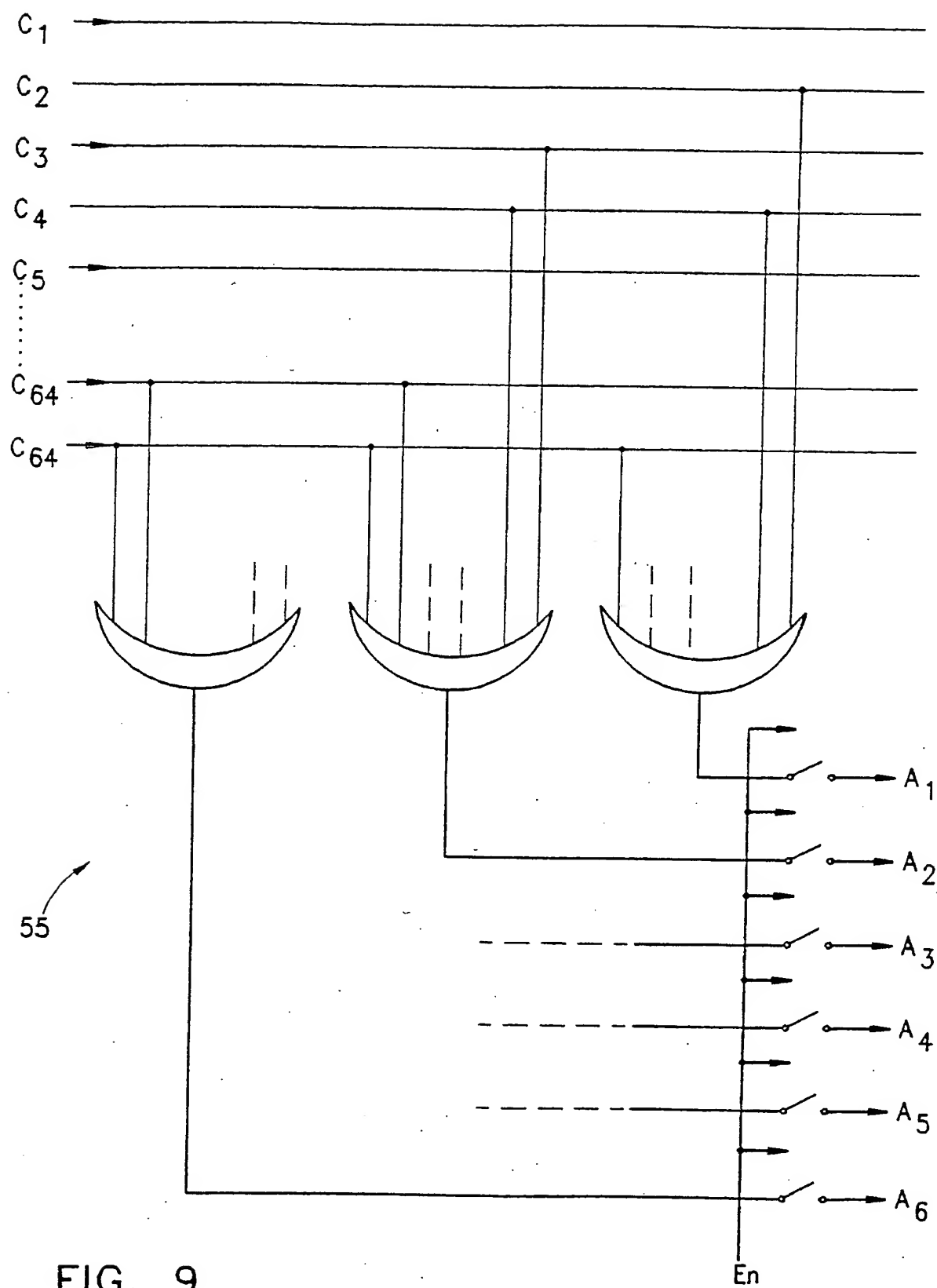


FIG. 9

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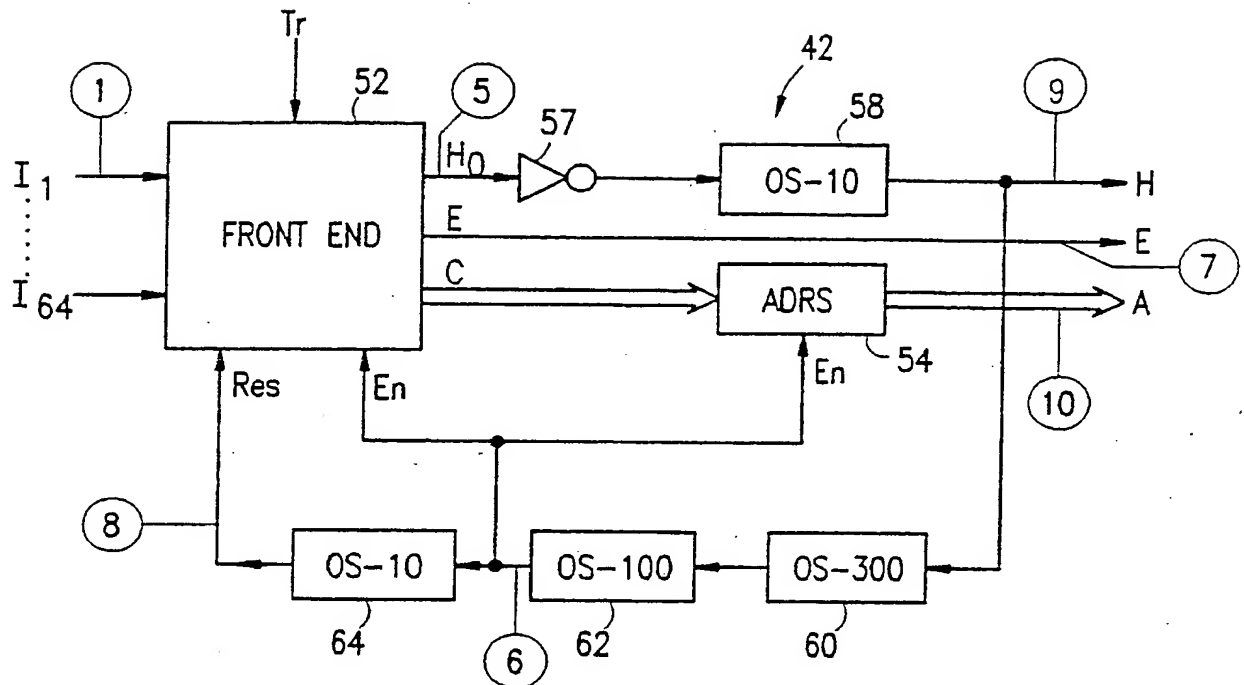


FIG. 10A

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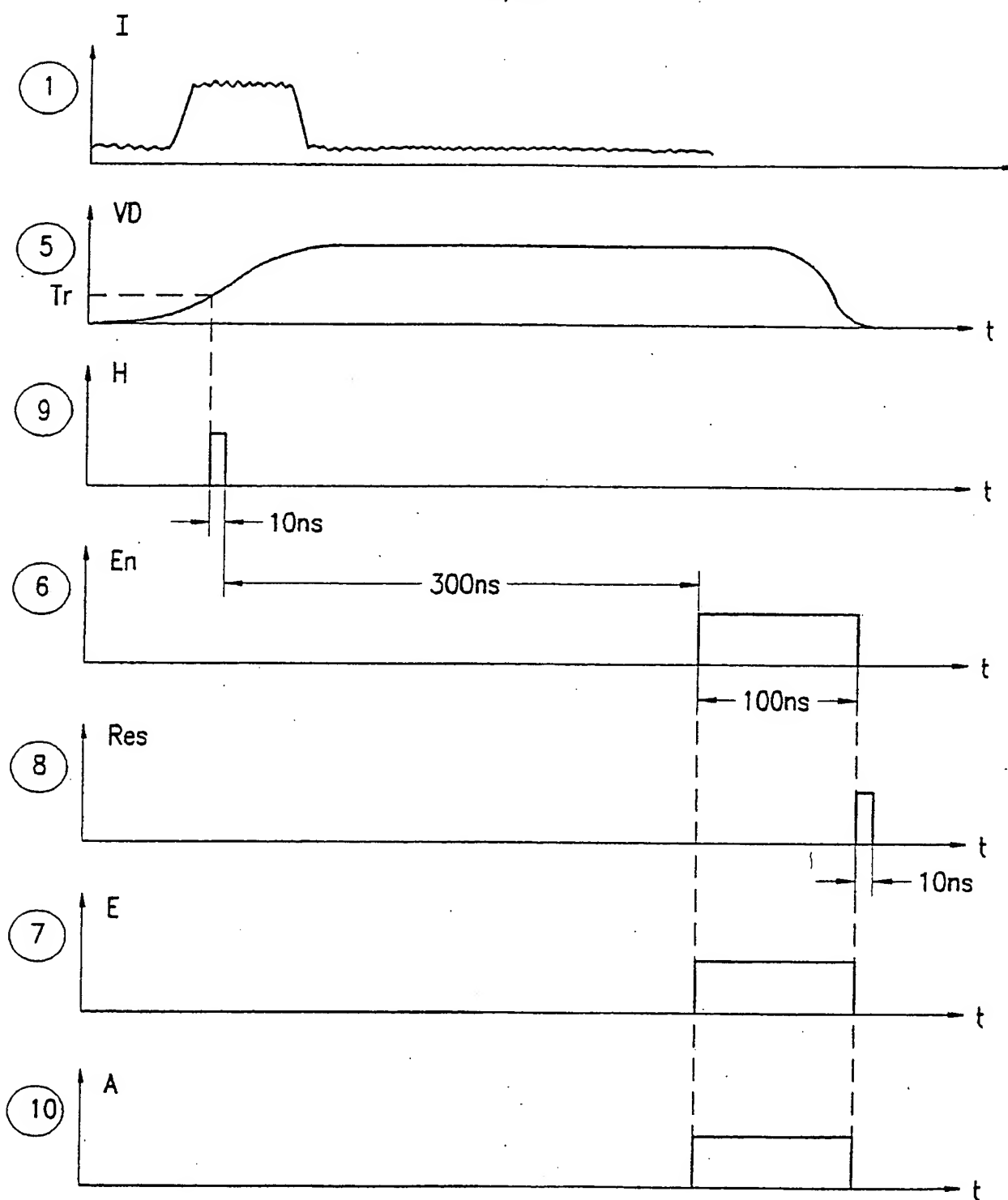


FIG. 10B

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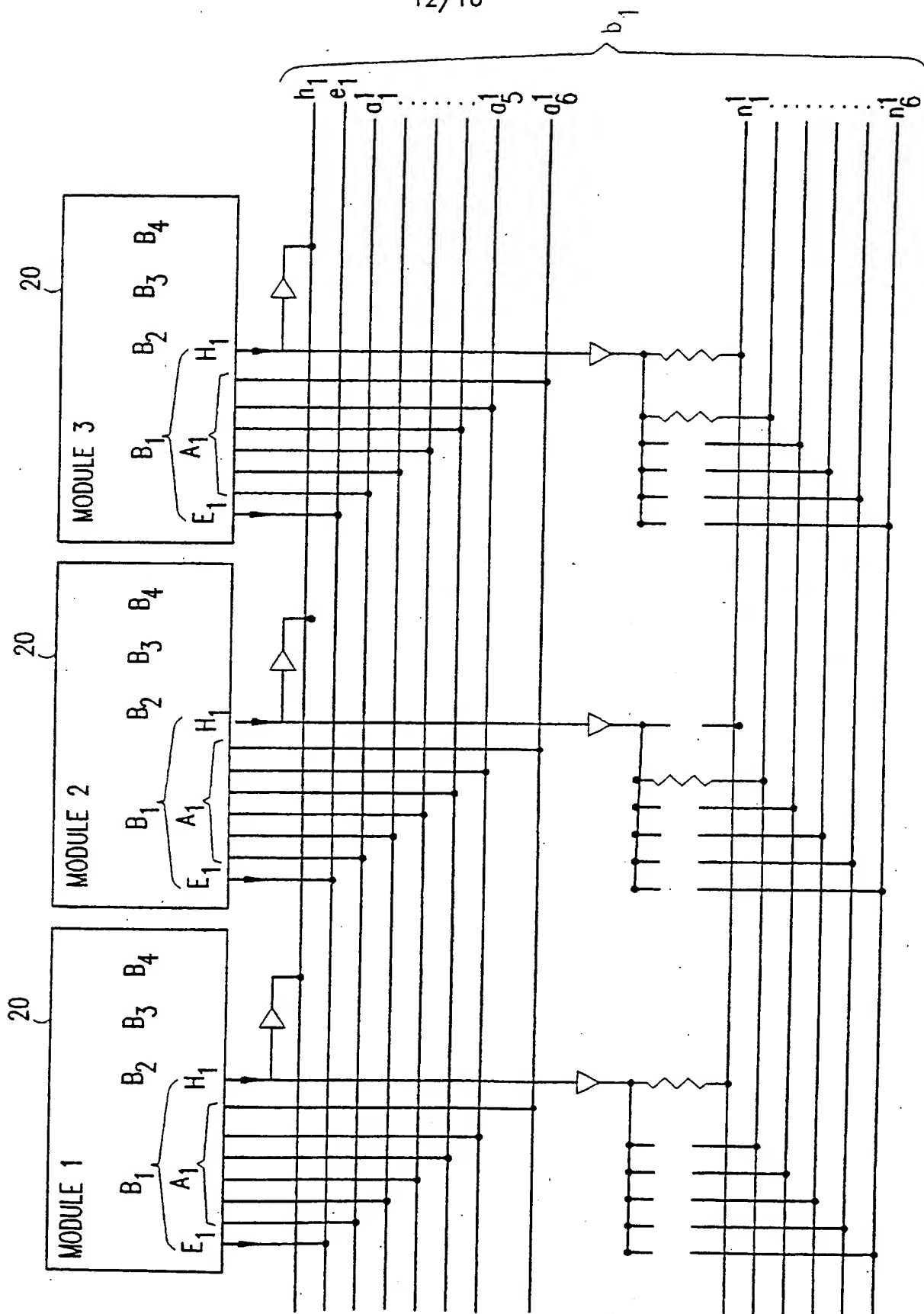


FIG. 11A

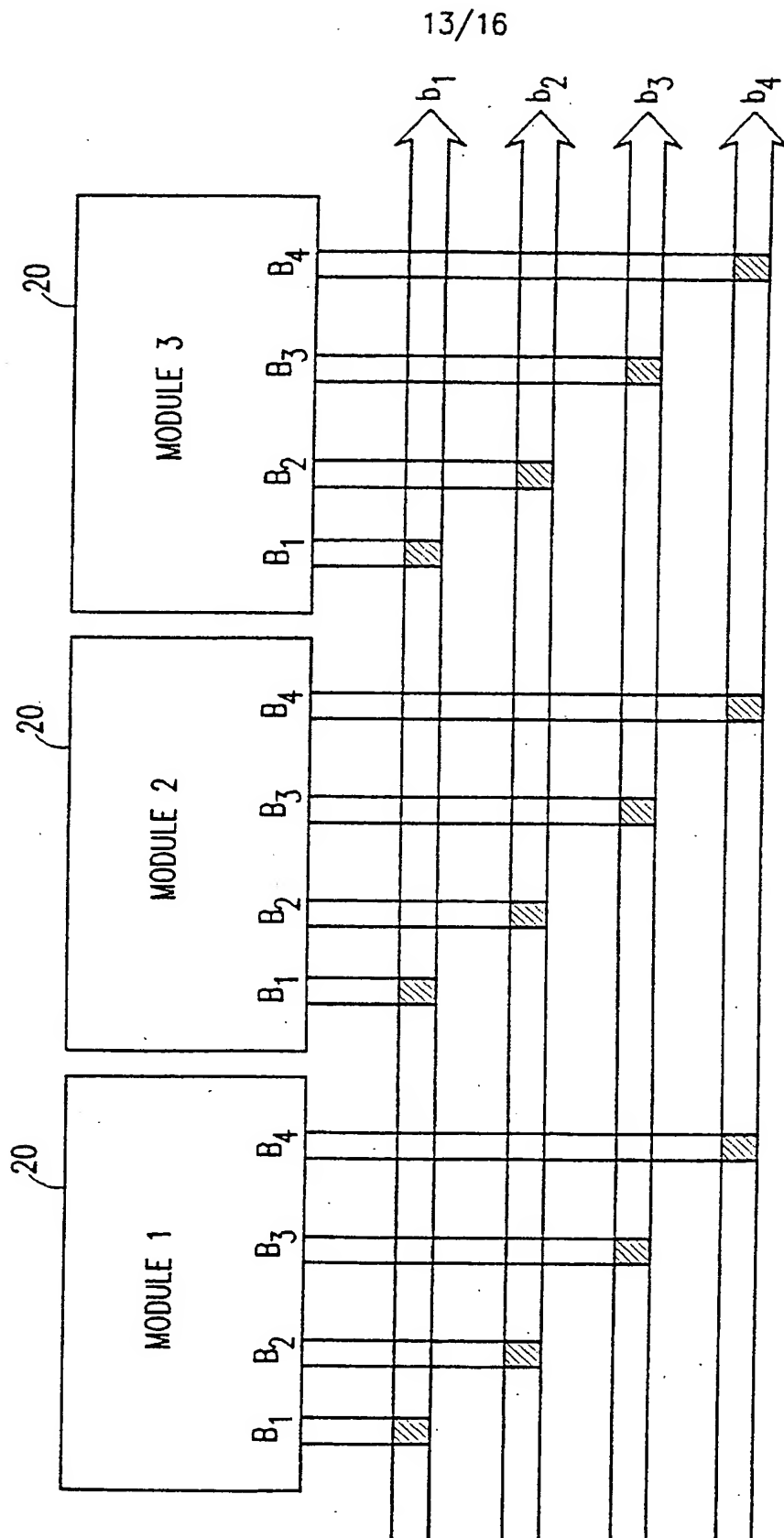


FIG. 11B

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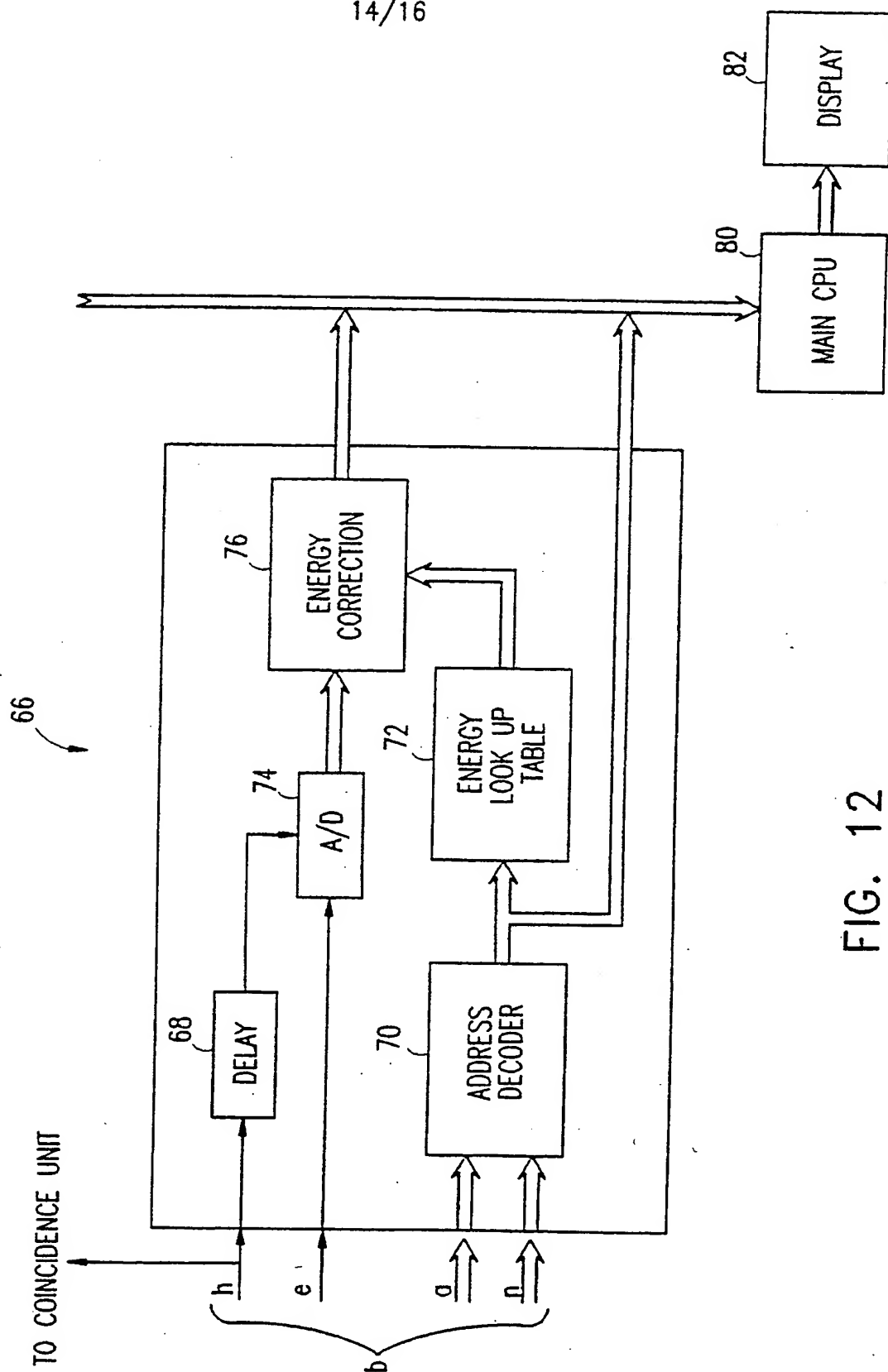


FIG. 12

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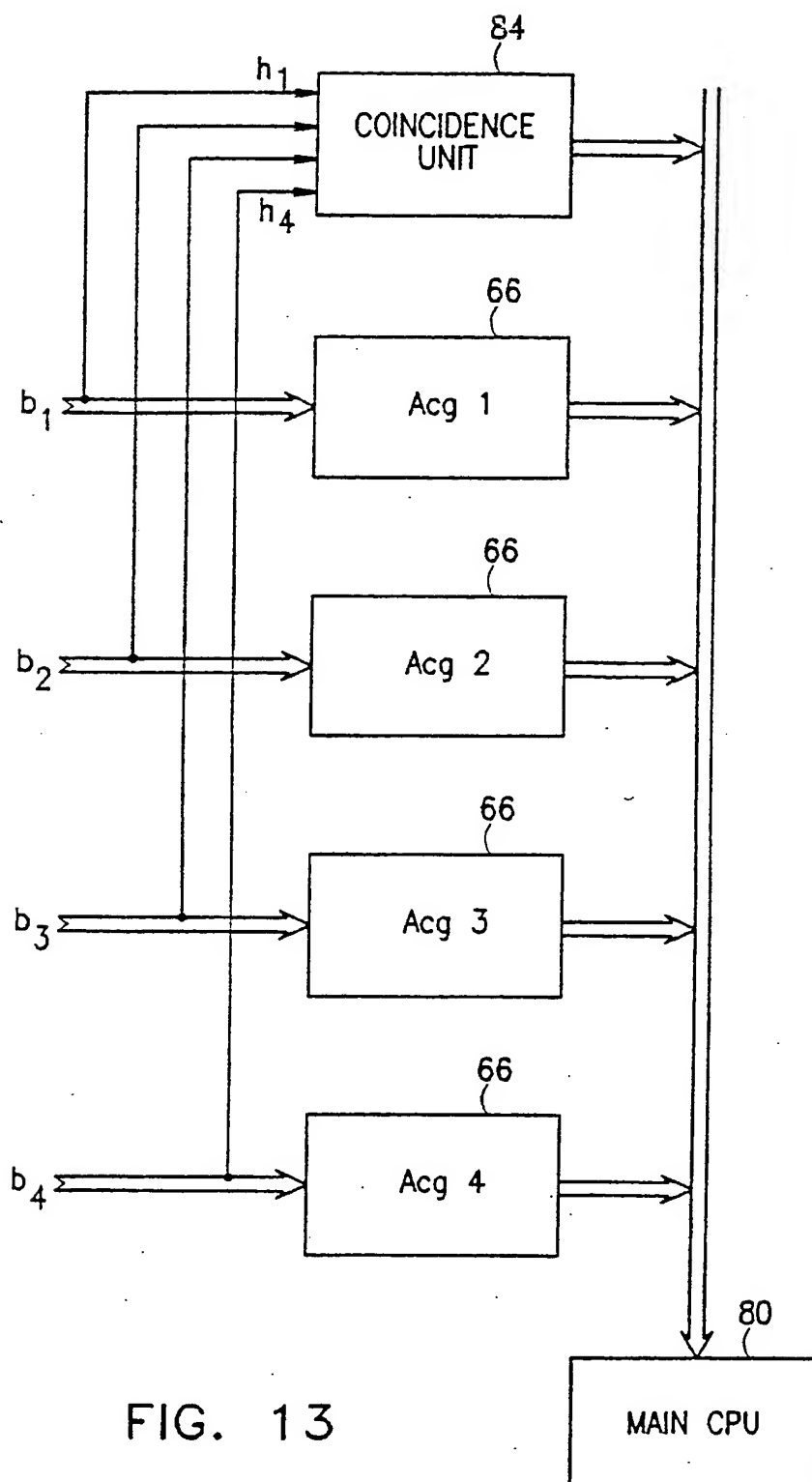
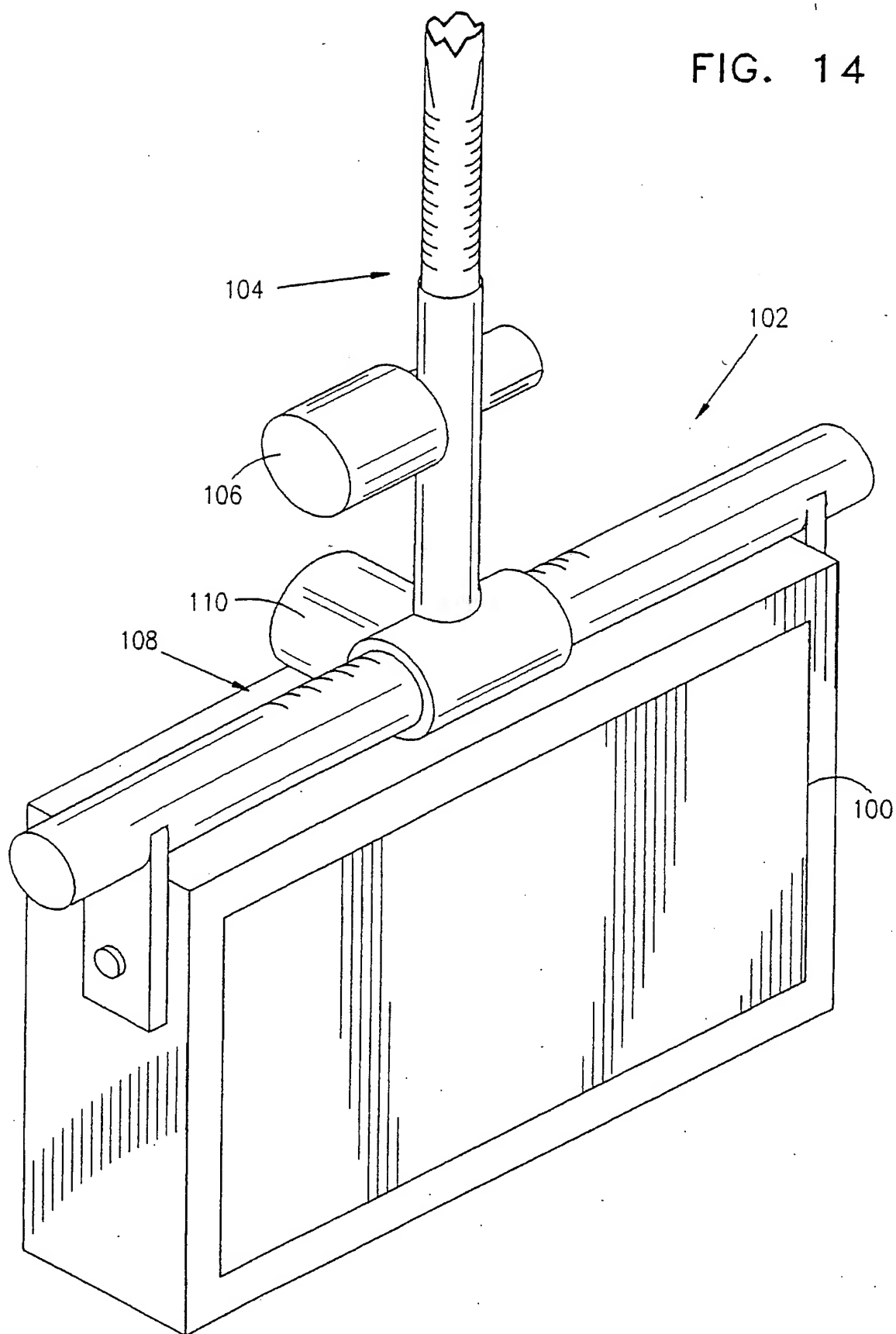


FIG. 13

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FIG. 14



INTERNATIONAL SEARCH REPORT

International Application No

PCT/IL 96/00164

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01T1/164 G01T1/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G01T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 262 383 A (SONY BROADCAST & COMMUNICATION) 16 June 1993 see abstract see page 3, line 26 - page 5, line 6 see page 9, line 1 - page 10, line 3 see page 15, line 32 - page 16, line 11 see figures ---	1,3,12, 25,44,48
A	US 5 548 122 A (SHOJI TAKASHI) 20 August 1996 see abstract see column 4, line 43 - column 5, line 7 see column 5, line 59 - column 6, line 50 see column 7, line 3 - line 60 see column 8, line 43 - line 63 see figures --- -/--	1,3,12, 25,44,48

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

14 August 1997

Date of mailing of the international search report

20.08.97

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Datta, S

INTERNATIONAL SEARCH REPORT

Intern. Application No.

PCT/IL 96/00164

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 4 432 059 A (INBAR DAN ET AL) 14 February 1984 see abstract see column 3, line 14 - column 4, line 42 see column 5, line 22 - column 7, line 13 see figures ---	1,3,12, 25,44,48
A	GB 2 289 979 A (SIMAGE OY) 6 December 1995 cited in the application see abstract see page 8, line 24 - page 10, line 16 see page 15, line 5 - page 16, line 23 see figures -----	1,3,12

INTERNATIONAL SEARCH REPORT

Information on patent family members

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